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CCSa Carbon Capture & Storage Association

Department of Energy & Climate Change

# CCS Cost Reduction Taskforce

## Final Report

May 2013

# The Potential For Reducing The Costs of CCS in The UK

**FINAL REPORT**
**PUBLISHED BY THE UK CARBON CAPTURE AND STORAGE COST REDUCTION TASK FORCE**

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**Jeff Chapman**
Chair – CCS Cost Reduction Taskforce, Chief Executive, Carbon Capture & Storage Association

Dr Jeff Chapman established the CCSA in 2006 with a group of 11 founder members. Since then the Association has grown to include 70 organisations consisting of representatives from oil and gas, power generation, coal, steel, cement, industrial gases, pipeline operators, shipping lines, equipment suppliers, contractors, management/environmental/engineering consultants, finance, insurance, law, regional agencies and academic institutions.

Jeff currently sits on various Committees, Steering Groups and Advisory Boards in the UK, Europe and internationally where his knowledge of CCS supports his advisory role in research and development and policy matters in relation to carbon capture and storage that are necessary to tackle the challenges of climate change to build a sustainable future.

In recognition of his services to the CCS sector Jeff has been awarded an honorary professorship at Nottingham University.

The then Energy Minister, Charles Hendry invited Jeff to lead the Government/Industry Cost Reduction Task Force in May 2012.

**Allan Baker**
Managing Director, Global Head of Power Advisory and Project Finance, Societe Generale

Allan Baker has worked at Société Générale for four years and has been involved in the power sector for more than 25 years, initially as an engineer and then in the finance sector. During his career he has advised on and financed projects in Europe, MENA, the US and Asia, and in sectors ranging from green-field renewable energy to the acquisition of large thermal power portfolios. This experience has also encompassed regulated, partially deregulated and merchant power markets. In recent years he has become a leading figure in the CCS area, having been instrumental in bringing the financing perspective to the policy debate based on his experience of advising on to two of the world's largest carbon capture and storage (CCS) projects and participation in the UK Government's CCS Development Forum.

Allan has a BSc (Hons) in Mechanical Engineering, an MBA, is a Fellow of the Institution of Mechanical Engineers and Chartered Engineer.

**Alastair Rennie**
Project Director, AMEC

Alastair Rennie worked initially for Halcrow on port design and BHP on coal development construction before joining AMEC in 1996 to project manage large integrated services work for Shell and BP. This was followed by work on supply chain management and leading projects for MoD work. In 2002 he worked on testing the options of new energy chains, such as conventional wind interfacing with wave power and hydrogen generation. He has led testing applications such as hydrogen fuelled standby power supply, and anaerobic test facilities (waste to methane, electricity to grid, heat and plant growth). He serves on the Board of the CCSA and chairs the H&S working group, with a particular interest in knowledge sharing. He also serves on the advisory board of the Scottish research centre for CCS.

**Thomas Stringer**
Director, R&D Carbon Capture Systems, Alstom

Tom Stringer is Director R&D for Alstom's Carbon Capture Systems. He has overall responsibility for developing Alstom's carbon capture technologies, which includes fundamental lab work, through process development, plant testing and validation. Tom is also responsible for the operations of Alstom's pilot and demonstration plants worldwide. He is based in Baden, Switzerland.

**Ian Donaldson**
Project Manager – CCS & Renewable Energy, The Crown Estate

Over the past 12 years, Ian has managed a variety of projects in a range of industries in both Australia and the United Kingdom; initially in the corporate development sector, followed by change management and information technology with his most recent 4 years being spent in the renewables sector at The Crown Estate. Ian's previous role was to manage the Offshore Wind Cost Reduction pathways development project which was released as a report to industry and government in 2012. Lessons learnt from that experience have been brought to bear in the development of this report.

**Jason Golder**
Senior Development Manager, The Crown Estate

Jason has worked for The Crown Estate for 22 years in a variety of roles but primarily in the offshore sector relating to marine aggregates, oil and gas pipelines, telecom cables, gas storage and for the past 9 years on $CO_2$ storage. Jason has been an ever present on the North Sea Basin task Force that has been in existence for 8 years and is now extended to 6 countries. Jason has led the negotiations for both of the existing lease agreements with Shell and National Grid as part of the commercialisation programme, as well as setting out the current leasing process.

**Patrick Dixon**
Expert Chair, Office of Carbon Capture and Storage, DECC

Patrick is currently Expert Chair of the Office of Carbon Capture and Storage (OCCS) and provides advice to Ministers and officials in DECC on CCS issues. He has had a career of more 30 years in the oil and chemical industries. Patrick is also a Non-Executive Director of the Nuclear Decommissioning Authority (NDA).

**Phil Hare**
Vice President, Pöyry Management Consulting

Dr Phil Hare is a Vice President in Pöyry Management Consulting and the Head of its NW Europe Region. He joined Pöyry 2004 and has over twenty five years' experience in the energy industry.

He specialises in corporate strategy, especially energy companies entering new business areas. He also leads the company's carbon capture and storage practice, which he has been involved with for six years advising private companies, regulators and Government departments. He has submitted evidence and spoken at various Government committees on energy matters as well as authoring influential reports.

Before joining Pöyry he held a variety of senior management posts at Powergen plc (latterly EON-UK) in both strategy and operational roles. Prior to this he worked for BP as a production engineer on both Forties and on gas installations in the Southern North Sea.

He is a frequent speaker at industry events in UK and elsewhere in Europe.

Phil has a BA (Hons) and D.Phil. from Oxford University.

**Stuart Murray**
Principal Consultant, Poyry Management Consulting

Stuart Murray joined Pöyry in 2005 and specialises in energy market modelling and asset valuation. Since 2008 he has advised on more than €26bn of renewable and conventional power asset transactions across Europe, North America and Asia. He has developed financial models for a variety of applications including due diligence processes, FEED studies and multilateral development bank funding applications.

Stuart is also an expert in the economics of Carbon Capture and Storage and has analysed various CCS concept projects in markets worldwide. Stuart has also presented papers on CCS economics at conferences in the UK and Canada and assessed the potential for CCS in delivering climate goals and decarbonising energy markets.

His clients range from major international utilities and financial institutions, to government departments including DECC, DEFRA and the Prime Minister's Office in the UK. Stuart holds a 1st Class Honours BSc. in Economics from University College London.

**Leigh Hackett**
Head of CCS, Alstom

Dr. Leigh A. Hackett is currently head of Alstom's Carbon Capture and Storage business. He spent 20 years in the technology and plant contracting business in the oil and gas, hydrocarbon and chemical processing industries, working in a number of countries, prior to joining Alstom in the Energy and Environmental Services division based in Switzerland. He has been focused on CCS since 2009.

He studied Chemical Engineering at the University of Manchester Institute of Science and Technology and graduated with a BSc in 1982, completing his MSc in 1983 and PhD in 1985.

Leigh Hackett is represented by Thomas Stringer, who leads on the Generation and Capture workstream.

**Mike Saunders**
President, Power & Process Europe, AMEC

Mike Saunders joined AMEC in 2007 to head up its global nuclear business. He was previously Senior Vice President of the Global Nuclear Fuel business at Westinghouse Electric Company. He has more than 30 years' experience in the nuclear power industry having held a number of senior positions including managing nuclear licensed sites in the UK, Europe and the US. He is a member of the board of the Sellafield parent company (Nuclear Management Partners).

Mike has an MBA and is a graduate of the Wharton Advanced Management programme. He is a chartered engineer and a Fellow of the Nuclear Institute.

Mike Saunders is represented by Alastair Rennie, who leads on the Infrastructure workstream.

**Paul Bryant**
Chief Executive Officer, CCS TLM

Paul Bryant joined CCS TLM following a 30-year career with BP during which he occupied various senior executive positions most recently with BP Alternative Energy. Until leaving BP, Paul was a Director of Hydrogen Energy International Limited, a joint venture he originated between BP and Rio Tinto where he was responsible for the Eastern Hemisphere and specifically the Hydrogen Power Abu Dhabi (HPAD) project, a 400MW Hydrogen Power project with CCS being jointly developed with the Abu Dhabi Future Energy Company (ADFEC) or Masdar. Prior to 2005 Paul was BP's Planning and Strategy Manager for its Wind and Solar businesses in London and spent almost 10 years in senior commercial roles in BP's Gas & Power and Upstream businesses in London, Aberdeen and Saudi Arabia.

Paul graduated with an Honours Degree in Mechanical Engineering and is a Fellow of the Institute of Mechanical Engineers.

**Ian Phillips**
Director, $CO_2$ DeepStore, a Petrofac company

Ian Phillips has 27 years experience in the upstream oil and gas industry, including 18 years with oil operating companies (Shell, BP, Marathon and Ramco) and 6 years with a major service company (Halliburton). In 2007 he became a founding Director of $CO_2$DeepStore Limited, one of the first companies specifically seeking to provide the service of $CO_2$ capture, transportation and deep geological storage. $CO_2$DeepStore was acquired by Petrofac Ltd in April 2010, giving the company the technical capacity and financial strength required to develop CCS projects. The company was a partner in the Scottish Power led CCS project consortium in the first UK CCS Competition.

Ian obtained an M.Eng. in Petroleum Engineering from Heriot Watt University, and an MBA through the Open University. He is also a Fellow of the UK Energy Institute and is a Chartered Petroleum Engineer.

**Bryony Livesey**
Head of Research and Technology, Costain

Dr Bryony Livesey joined Costain in 2012 and has responsibility for technology development in the power, nuclear process and hydrocarbons & chemicals sectors. She joined Costain from Doosan Babcock where she established their Global R&D Centre for clean energy. Bryony previously worked for AEA Technology, leading technology and innovation in senior management roles both in the UK and internationally. She was President of a joint venture between AEA Technology and Sumitomo Corporation based in Japan. In this role, she led the development of joint UK-Japan projects across a wide range of industry sectors, working with R&D organisations and academic institutions from across UK, Europe and North America.

Bryony is a Chartered Engineer with a BSc from Manchester University and a PhD from Cambridge University.

**Angela Whelan**
Chief Executive Officer, Ecofin Research Foundation

Angela is Chief Executive of the Ecofin Research Foundation. The Foundation was founded in 2008 by Ecofin Limited to accelerate the transition to a low carbon economy.

Prior to setting up the Foundation she spent five years as a portfolio manager at Ecofin Limited, an independent investment management firm which specialises in the global utility, alternative energy, infrastructure and environmental sectors.

From 1989 to 2003 Angela was a financial analyst specialising in the utility sector with several investment banks including Barclays de Zoette Wedd, Credit Lyonnais Securities Europe and Cazenove. At Credit Lyonnais she was head of UK equity research and a member of the Executive Management Committee.

Angela has a BA in Economics from Carleton University, Canada and an MA and DPhil in Economics from the University of Sussex.

**David Clarke**
Chief Executive, ETI

David Clarke joined the Energy Technologies Institute (ETI) as Chief Executive Officer in January 2008 from his previous role as Head of Technology Strategy at Rolls-Royce plc. He has been involved in collaborative research and development of advanced technologies for over 25 years. He is a member of the UK Energy Research Partnership and was part of the UK Government Offshore Wind Cost Reduction Task Force. He has been a member of the UK EPSRC Council and of advisory bodies for a number of leading academic institutions, UK government agencies and the European Commission.

David is a Fellow of the Royal Academy of Engineering, of the Institute of Materials, Metals and Mining, and the Energy Institute. He graduated in Materials Technology from the University of Surrey, has a PhD in Composite Materials and is a Chartered Engineer.

**Jim Ward**
Head of CCS, National Grid Carbon

Jim Ward is Head of CCS at National Grid having led the activity since project inception in 2007. He graduated in Chemical Engineering from Imperial College following which he worked for BP in commercial oil and gas midstream roles in Europe and Asia. He has subsequently held director posts in a power generation business in Australasia and then BG Storage, prior to joining Transco (now National Grid) in 2002. Having managed sales of gas transmission capacity and the emissions portfolio, Jim led a review of future capacity use which led to the initiation and development of National Grid's CCS strategy.

**Richard Metcalf**
Partner, Norton Rose

Richard Metcalf is a projects lawyer based in London. With more than 30 years of experience in the field of energy-related projects, with particular reference to oil and gas exploration and development and power generation, the legal challenges of carbon capture and storage are a natural extension to his practice. Richard leads a team at Norton Rose which advises both Government and industry, on the legislative and regulatory structuring of energy projects as well as their development, financing and implementation.

**Colin Imrie**
Scottish Government

Colin Imrie is Head of the Scottish Government's Energy and International Low Carbon Division. He also supports the work of the Scottish Energy Advisory Board and its industry advisory groups on Renewable Energy, Oil and Gas and Thermal Generation and CCS. He leads on Scottish international low carbon work, coordinates European Union related work on energy and climate change for the Scottish Government and was seconded to the EU Presidency team at the UN Climate Change talks in Doha. He has worked in the Foreign and Commonwealth Office and European Commission and has served as Energy and Nuclear attaché for the UK Permanent Representation in Brussels, when he chaired the Council Energy Working Group during the UK Presidency in 1998. He is a Director of the Scottish European Green Energy Centre (SEGEC).

**Mike Farley**
Consultant Scottish Enterprise/Industry & Power Association

Dr Mike Farley was until recently Director of Technology Policy Liaison at Doosan Power Systems, which is a leading developer of carbon capture systems (Post Combustion and OxyCoal). He chairs the Industrial Leadership Group on Thermal Generation and CCS in Scotland - a joint Scottish Government and Scottish Enterprise initiative, and represents Scottish Enterprise on the CCS Cost Reduction Task Force.

### Wilfried Maas
General Manager, Carbon Capture Demonstration, Shell

In his current role as General Manager Carbon Capture Demonstration at Shell, Wilfried Maas supports the technical development of Shell's global portfolio of CCS demonstration projects. He previously led the team which developed and implemented GHG and Energy Management plans for upstream and downstream operating assets and projects and which executed the front end development of a multisite, multi projects Energy Efficiency & GHG reduction capital program. His previous roles covered project technology integration, energy efficiency program management, process design, manufacturing and process development R&D. He studied Physical Chemistry and holds a PhD in Physical organic chemistry.

In addition to Wilfried's expertise on capture technology, **Dr Owain Tucker**, Global Deployment Leader for Shell CCS and Contaminated Gas, provided detailed storage development knowledge, and **Belinda Perriman**, Shell's Opportunity Manager for the Peterhead CCS project, provided detailed commercial experience. **Lynsey Tinios**, Regulatory Affairs Manager at Shell, and **Alexander Ratcliffe**, Policy Analyst at Shell, also provided valuable input to the work of the Task Force.

### Luke Warren
Deputy Chief Executive, Carbon Capture and Storage Association

Luke Warren is the Deputy Chief Executive at the Carbon Capture and Storage Association and joined the association in 2009. Luke works on a wide range of policy issues for the CCSA, including UK Electricity Market Reform, CCS regulations, European CCS activities as well international bodies working on CCS and climate change issues. In his role he has provided evidence to Governments, developed multiple papers and spoken widely on CCS matters. He is regularly invited to participate in various national and international activities and groups that promote CCS as a response to concerns over climate change.

Prior to joining the CCSA Luke worked in a number of positions in the energy industry.

Luke has a PhD in Biological Sciences from University College London and a Degree in Environmental Sciences from Queen Mary, University of London.

### Andy Read
Capture Director for the Maasvlakte CCS (ROAD) Project, E.ON

For the last five years, Andy Read has focused on CCS project development leading projects at Killingholme and Kingsnorth in the UK, and now as Capture Director for the E.ON / GDF SUEZ joint venture at Maasvlakte, Netherlands (ROAD Project). He has previously worked on several new build projects, most notably the early development of the 1275MW Grain CHP plant, and acted as interface between commercial functions (such as Strategy and Trading) and the power plant asset managers. Andy's experience also includes the design and operation of supercritical coal power plant and a stint on an operating coal-fired power station.

He is a Chartered Member of the Institute of Physics and holds an M.A.(Hons Cantab) in Natural Sciences (Physics) and a Ph.D. (Cantab) in Physics.

### Anne S. Lycke
Vice President Asset Management, Gassnova

Anne S. Lycke has extensive experience along the entire value chain from exploration, project development, production and gas management through joint venture work and asset management in international business environment in the oil and gas and renewable energy sectors. Before joining Gassnova, Anne previously worked for 30 years in Hydro and Statoil.

Eirik Harding Hansen, Asset Manager, $CO_2$ Transport & Storage, Gassnova, also provided a valuable contribution to the work of the Task Force.

### Peter Whitton
Managing Director, Progressive Energy

Peter Whitton is the founder and Managing Director of Progressive Energy and has 30 years experience in the electricity and energy supply. Progressive Energy Ltd is a clean energy project development company which specialises in the development of CCS projects. He is also a Director of a wind development company, Pennant Walters Limited. Previously Peter held senior management and executive positions in several utility companies undertaking commercialisation of emerging technologies, project management, project and business financing, commercial management & negotiation, business strategy, and Government relations.

**Professor Stuart Haszeldine**
University of Edinburgh
Scottish Carbon Capture and Storage

Stuart Haszeldine is the current Director of Scottish Carbon Capture and Storage (SCCS) and the world's first Professor of CCS. He is one of the key driving forces behind establishing CCS as a new industry in the UK, EU and worldwide. Stuart has over 35 years research experience in energy and environment; innovating new approaches to oil and gas extraction, radioactive waste disposal, carbon capture and storage, and biochar in soils. Stuart provides advice to both UK and Scottish governments. He was elected FRSE in 2002, awarded the Geological Society William Smith Medal in 2011 and in 2012 was appointed OBE for services to climate change technologies.

**Chris Littlecott** also provided valuable input to the work of the Task Force for SCCS.

Chris is a Policy Research Associate with the Scottish Carbon Capture and Storage academic consortium, and a Senior Policy Advisor at independent environmental organisation E3G. He was previously senior policy adviser at Green Alliance from July 2008 to March 2012, leading work on EU policy and carbon capture and storage.

**George Clements**
CCS Development Manager,
SSE Thermal Development

George Clements is CCS Development Manager for SSE having led SSE's involvement in the Peterhead project from project inception. He graduated with a B Eng (Hons) degree in Mechanical Engineering from Strathclyde University in 1987 as a mature student after previous engineering training with the merchant navy.

He has worked for SSE and its predecessor companies since leaving university and has fulfilled a number of different operational management roles within SSE' s UK thermal gas fleet including senior management roles within Peterhead Power Station. Recent activity has been in the development activities for SSE's thermal generation portfolio assuming the role for the Peterhead CCS project in 2010.

**Torgeir Melien**
Leading Analyst – CCS Economics,
Statoil ASA

Torgeir Melien is currently a CCS Economics analyst at Statoil. He was a member of EU-ZEP TaskForce on CCS/Capture Cost in 2009-11, and the TeamLead of the TechnoEconomics Team of the Joint Industry "$CO_2$ Capture Project" (CCP), 2002-04 (phase1) and 2007-09 (phase2). He has 30 years of experience from various Oil & Gas and Energy business units of Norsk Hydro and Statoil, and has a MSc degree in Economics from University of Oslo.

**Claude Heller**
Programme Director, Air Liquide

Claude Heller holds an Engineering Master Degree from Ecole Centrale de Paris (1977). He is currently Air Liquide R&D Program Director, covering Energy and Process Industries. He started his career at Air Liquide R&D to develop technologies for the metals market. He brings a very broad experience in general management and leadership, technology and business development in industry. In 2005 he launched Air Liquide's gas activities in Russia.

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[20] Source: UKERC, 'Investment in electricity generation: the role of costs, incentives and risks', 2007

Image provided by ETI

# Executive Summary Final Report

*This Final Report builds on the Interim Report of November 2012 which focused on identifying the opportunities for cost reduction across the CCS chain to achieve cost competitive CCS in the 2020s. The Final Report presents to Government what the Task Force has identified as Agreed Actions and recommended Next Steps to achieve these cost reductions and develop the CCS industry in the UK.*

## Key Conclusion of the Interim Report is unchanged

The Key Conclusion of the Interim Report of the UK CCS Cost Reduction Task Force (CRTF) remains intact. This is:

> UK gas and coal power stations equipped with carbon capture, transport and storage have clear potential to be cost competitive with other forms of low-carbon power generation, delivering electricity at a levelised cost approaching £100/MWh by the early 2020s, and at a cost significantly below £100/MWh soon thereafter.

The contents of the Interim Report of the CRTF remain largely unchanged. The work of the CRTF over the last four months, and this Final Report, have built on the Interim Report findings by:

- converting the Interim Report Candidate Actions into Agreed Actions; and
- laying out the Next Steps which should be followed to develop the CCS industry in the UK, to enable the roll-out of follow-on projects after the DECC Commercialisation Programme projects and ultimately to deliver cost-effective CCS in the UK.

This Final Report Executive Summary now appears before the Interim Report Executive Summary. A new Chapter 7 has been added to the body of the Report, showing the detail of the work done on the Agreed Actions and Next Steps.

## UK CCS Commercialisation Programme outcome

On 20 March 2013, the UK Government announced that it was taking two Preferred Bidders forward, with a view to concluding FEED contracts with those bidders, and if successful leading to delivery of up to two full chain CCS projects.

The Government's key objective for these projects is that they contribute to the achievement of the 'Outcome' – the deployment of cost-effective fossil fuel generation with CCS in the UK in the early 2020s. The plan for leveraging these projects to achieve the Outcome has yet to be published by Government; it will ultimately facilitate the creation of a legacy of infrastructure that future projects can use to minimise costs and investment risk. An important additional benefit will include the active dissemination (within IP boundaries and in an agreed structured process) of the knowledge and experience developed.

Once these projects are under development the intention is that investment in follow-on CCS projects will be stimulated by reforms currently taking place to the electricity market that are intended to bring forward investment in all low carbon forms of electricity generation, including generation with CCS.

## Seven key next steps to support the large scale development of power and industrial CCS in the UK

The CRTF believes that the following seven key steps will be required if follow-on and future UK CCS projects are to be developed which deliver the identified cost reductions.

1. **Ensure optimal UK CCS transport and storage network configuration**
   Conduct industry-led but government supported studies to identify options for developing configurations for the UK CCS transport and storage system for both early CCS projects and future CCS projects, in order to minimise long-run costs. Take into account likely future development of $CO_2$ storage hubs and the related pipeline networks. *(Led by UK $CO_2$ Storage Development Group.)*

2. **Incentivise $CO_2$ EOR to limit emissions and maximise UK hydrocarbon production**
   Create a UK tax regime to support the development of brownfield $CO_2$ Enhanced Oil Recovery *($CO_2$ EOR) in the UK North Sea. (Oil Companies, OCCS, DECC EDU.)*

3. **Ensure funding mechanisms are fit-for-purpose**
   Continue work to develop the coal and gas CfD structures, and other relevant EMR and funding instruments, ensuring their suitability for widespread use in coal and gas CCS projects. *(DECC, CCSA, UK CCS Commercial Development Group.)*

4. **Create bankable contracts**
   Focus on how to construct contracts (including the detailed terms of CfDs) that will be needed to make follow-on projects bankable. This will include taking evidence from the published Commercialisation Programme ITPD, the

experience of the Commercialisation Programme bidders and input from other stakeholder including finance and insurance sectors. *(UK CCS Commercial Development Group.)*

5. **Create a vision for development of CCS Projects in the UK from follow-on projects through to widespread adoption**
   Create an industry-led and government-supported vision of how subsequent phases of CCS projects in the UK can be developed and financed. The aim is to encourage and guide developers who are bringing the next UK CCS projects forward, that will get a CfD but no government grant. *(CCSA, The Crown Estate, DECC.)*

6. **Promote characterisation of $CO_2$ storage locations to create maximum benefit from the UK storage resource**
   Examine the options for characterisation of both storage areas and also specific sites for $CO_2$ storage in the UKCS, and recommend a way forward to Government and industry. The aim is to reduce the ‘exploration risk’ premium, thereby making storage sites bankable both commercially and technically. *(UK $CO_2$ Storage Development Group.)*

7. **Create policy and financing regimes for CCS from industrial $CO_2$**
   Create proposed policy and financing regimes for the CCS of Industrial $CO_2$. *(BIS, CCSA and DECC.)*

## New organisational structures

The UK CCS Cost Reduction Task Force, having delivered on its terms of reference, will disband following publication of this report. To ensure the actions are delivered, the Task Force recommends the following national leadership groups be created to take forward the recommendations:

A. **The ‘UK $CO_2$ Storage Development Group’.**
   This group will be led and co-ordinated by The Crown Estate. The aim of the group will be to unlock cost reductions through the benefits of scale and to reduce risks in the $CO_2$ storage and transport sector.

B. **The ‘UK CCS Commercial Development Group’.**
   This group will involve active Bank and Insurance industry participants. The group will be established by CCSA, the Energy Technologies Institute, The Crown Estate and the Ecofin Foundation, and be led by the Ecofin Foundation. The aim of the group will be to secure ways, together with the UK Government, of making UK CCS projects bankable, and reducing their cost of capital.

C. **The UK CCS Knowledge Transfer Network.**
   This will be led by the CCSA. Its aim will be to enhance cost saving (and value enhancing) potential for CCS projects by promoting and facilitating the flow and review of knowledge and information, for both Industry and Government, following on from early projects in the UK and elsewhere. This will identify key gaps that stakeholders should address in order to ensure that CCS plays its full potential in the broader decarbonisation of the UK energy system.

These groups should provide input to an Industry-Government partnership forum which will monitor progress in delivering the actions as well as looking at development strategically, beyond the initial next steps identified.

## Additional supporting steps to underpin early phase UK CCS projects

In additional to the seven Key Next Steps shown above, the CRTF has agreed that the following 26 Supporting Steps are important and should also be taken, in order to mitigate investor and operational risks and underpin successful development of follow-on and future UK CCS projects.

### Storage and transport

**Ensure optimal UK CCS transport and storage network configuration**

- Create the UK $CO_2$ Storage Development Group. *(Crown Estate, see above.)*

**Facilitate potential $CO_2$ injection into multiple stores**

- Ensure contracts, licences and leases (for Commercialisation Programme projects and beyond) are structured to allow $CO_2$ to be injected into alternative stores, by agreement between storage owners. *(OCCS, DECC, The Crown Estate.)*

### Generation and capture

**Increase scale of generation and capture plant**

- DECC should not introduce arrangements that limit the size of plant for follow-on and future project development. This will enable Project developers to make the right economic choice for their project without being constrained by artificial limits.

**Optimise plant design requirements and specifications**

- Implement a Knowledge Transfer Network. (*CCSA,* see above.)

- Facilitate sharing experiences/issues on product and process design specifications, scale-up, constraints etc. Also review the design requirements of the DECC Commercialisation Programme competition to identify any specifications that have been or should be changed. *(UK CCS Knowledge Transfer Network.)*

**Examine benefits and downsides of generation and capture integration**

- Commission a report that examines the benefits and downsides of integration from the experience of all early projects, world-wide, in order to channel this experience into future designs. Explore the potential to collaborate with GCCSI and/ or ZEP. *(UK CCS Knowledge Transfer Network.)*

**Continue R&D funding for future technologies**

- The Advanced Power Generation Technology Forum (APGTF) and DECC, in consultation with industry (CCSA) and academia (the UK Carbon Capture and Storage Research Centre), should prepare a realistic analysis of the current R&D situation and its future requirements. *(APTGF and DECC.)*

- R&D for capture technologies (1st, 2nd and 3rd generation) should continue from both industry and Government with funding focused on the priorities identified in an updated R&D needs matrix. *(APTGF.)*

## Commercial and financial

**Develop business models for CCS cluster development**

- Facilitate knowledge transfer of current (and proposed) business models for the addition of multiple stores and multiple capture units onto existing networks and hubs. Developing an understanding of these business models will enable 'next phase' projects to fully benefit from existing and planned infrastructure. *(UK CCS Knowledge Transfer Network.)*

- Scottish Enterprise to feedback to the UK $CO_2$ Storage Development Group and Knowledge Transfer Network with regard to next steps for future business models for CCS. *(Scottish Enterprise.)*

- Examine options for public and private sector roles in co-ordinating/facilitating the efficient development of CCS clusters, *(UK CO2 Storage Development Group.)*

**Ensure funding mechanisms are fit for purpose**

- CCSA to encourage successful projects and Government to be transparent in the structuring, composition and design of their CfDs to allow future projects and financiers to fully understand the nature of their investments. This step can also be potentially fed back into and be facilitated by the Knowledge Transfer Network. *(CCSA, Knowledge Transfer Network, UK CCS Commercial Development Group.)*

- Recognise that early follow-on projects may have unique first of a kind risks that may require a contract structure closer to the DECC Commercialisation Programme framework rather than the final long term structure. Ensure this is fully taken into account for the next projects. *(DECC.)*

**Ensure continued involvement from financial and insurance sectors**

- Create the UK CCS Commercial Development Group. *(Energy Technologies Institute, The Crown Estate and Ecofin Foundation,* see above.)

## Cross-cutting issues

**Continue to develop a UK CCS policy and regulatory framework**

- Continue engagement between government, industry and finance sectors to ensure that future development of the policy and regulatory regime is suitable to deliver CCS projects, informed by an understanding of the role that CCS can play in the broader decarbonisation of the UK energy system. In this regard, consider coordination of a study drawing on a broad range of perspectives, scenarios (about the future role of CCS) and relevant experiences from other sectors. *(CCSA, DECC, UK CCS Commercial Development Group.)*

- Continue engagement and two-way information flow with DECC, MMO and DEFRA on the marine requirements of CCS developers. Ensure that MCZs are managed so that $CO_2$ transport and storage can be effectively deployed. *(CCSA, The Crown Estate.)*

- Industry experts to work together to understand the genuine extent of storage liabilities and to seek reform to existing arrangements if justified. *(UK $CO_2$ Storage Development Group, UK CCS Commercial Development Group.)*

**Develop spatial planning and consenting regimes for the CCS industry**

- Streamlining of the CCS planning and consenting process, including the provisioning of a guide to be produced as part of the Commercialisation Programme. *(DECC.)*

- Transfer 'lessons learned' from wind, wave and tidal consenting procedures. Make recommendations for improving the National Policy Statement for Fossil Fuel Power Generation. *(DECC, The Crown Estate.)*

- Review and improve the National Policy Statements for Fossil Fuel Power Generation to ensure they are updated to include developments and requirements for CCS. *(DECC, CCSA, The Crown Estate.)*

**Optimal strategy for locating fossil power stations for CCS**

- Following on from work already underway, recommend whether there is an optimal strategy for locating future CCS plant (generation, capture, transport and storage), to optimise fuel transport to storage hubs, electricity transport, $CO_2$ transport and water use across the UK, in order to minimise the long-run cost of low carbon power generation. *(ETI.)*

**Assess wider energy system benefits**

- Publish a report from analysis currently underway, investigating the impact of CCS on overall energy system costs (including power, transport, industry and heat) under a series of alternative deployment and intermittency scenarios. *(ETI.)*

**The value of CCS flexibility to the power sector**

- Conduct a study on the limits of and costs to making coal and gas power plants equipped with CCS as flexible as current non-CCS power plants. (DECC and *Industry coordinated by the Knowledge Transfer Network.)*

- Based on the findings of the above study, commission a consultant study to look at the economic and commercial value of CCS flexibility to the power sector as a whole, with reference to power storage as the functional alternative. *(DECC.)*

**Incentivise $CO_2$ EOR to limit emissions and maximise UK hydrocarbon production**

Consider potential synergies and cost benefit of $CO_2$ EOR with alternative storage solutions. *(UK $CO_2$ Storage Development Group.)*

# Executive Summary Interim Report

## Introduction

Electricity generation in the UK is on the brink of a radical transition driven by the Government's ambitious carbon reduction targets, and retirement of ageing coal, nuclear and gas plant. A majority of the current base load generation fleet will require replacement before 2030, and if the UK is to reach its 80% GHG emissions reduction target by 2050, significant decarbonisation of the entire energy sector will be needed at the same time.

The twin requirement to replace ageing plant, and to reduce $CO_2$ emissions, can be turned into an advantageous infrastructure investment in Carbon Capture and Storage (CCS), to enable long-term use of fossil fuels in a carbon-constrained economy, alongside renewable and nuclear power, and to generate 'Green Growth' for the UK economy.

Energy system modelling by the Energy Technologies Institute suggests that successful deployment of CCS would be a major prize for the UK economy, cutting the annual costs of meeting carbon targets by up to 1% of GDP (or around £42 billion per year) by 2050.

The availability and scale of high quality geological storage beneath the UK continental shelf in the North Sea and East Irish Sea, and the UK's well established offshore oil and gas expertise means that CCS represents an opportunity to drive UK economic growth, to retain and grow employment opportunities, to protect and grow the UK's manufacturing base and to gain significant competitive advantage in manufacturing costs over other countries in Europe. This gives the UK a unique position within Europe.

There is also an important and valuable opportunity to exploit the symbiosis between CCS and $CO_2$ EOR in the UKCS, adding significant revenues to a number of projects and extending the productive life of several UK oilfields. This is a key driver for CCS in the US and Canada, and it may be possible to achieve analogous benefits in the UK.

And in the longer term the UK might choose to sell a storage service to other EU countries to reduce their own emissions, and to export UK CCS-related services across the globe.

## The Task Force

The CCS Cost Reduction Task Force was established in March 2012 by DECC to advise Government and Industry on the potential for reducing the costs of CCS, so that CCS power projects are financeable and competitive with other low carbon technologies in the early 2020s.

The Task Force comprises 30 members from the engineering, hydrocarbon, finance, project developer and academic sectors, representing a broad spectrum of UK and international organisations with deep experience in all aspects of CCS.

This Interim Report describes the work undertaken by the CCS Cost Reduction Task Force to date. The report describes the sources of potential cost reduction, along with the key enabling actions required to deliver them.

## Key conclusion

It is the conclusion of the Task Force that:

> UK gas and coal power stations equipped with carbon capture, transport and storage have clear potential to be cost competitive with other forms of low-carbon power generation, delivering electricity at a levelised cost approaching £100/MWh by the early 2020s, and at a cost significantly below £100/MWh soon thereafter.

In essence, these costs of electricity can be achieved in the early 2020s through:

1 a. investment in large CO2 storage clusters, supplying multiple $CO_2$ sites;

b. investment in large, shared pipelines, with high use;

2 investment in large power stations with progressive improvements in $CO_2$ capture capability that should be available in the early 2020s;

3. a reduction in the cost of project capital through a set of measures to reduce risk and improve investor confidence in UK CCS projects; and

4. exploiting potential synergies with $CO_2$-based EOR in some Central North Sea oil fields

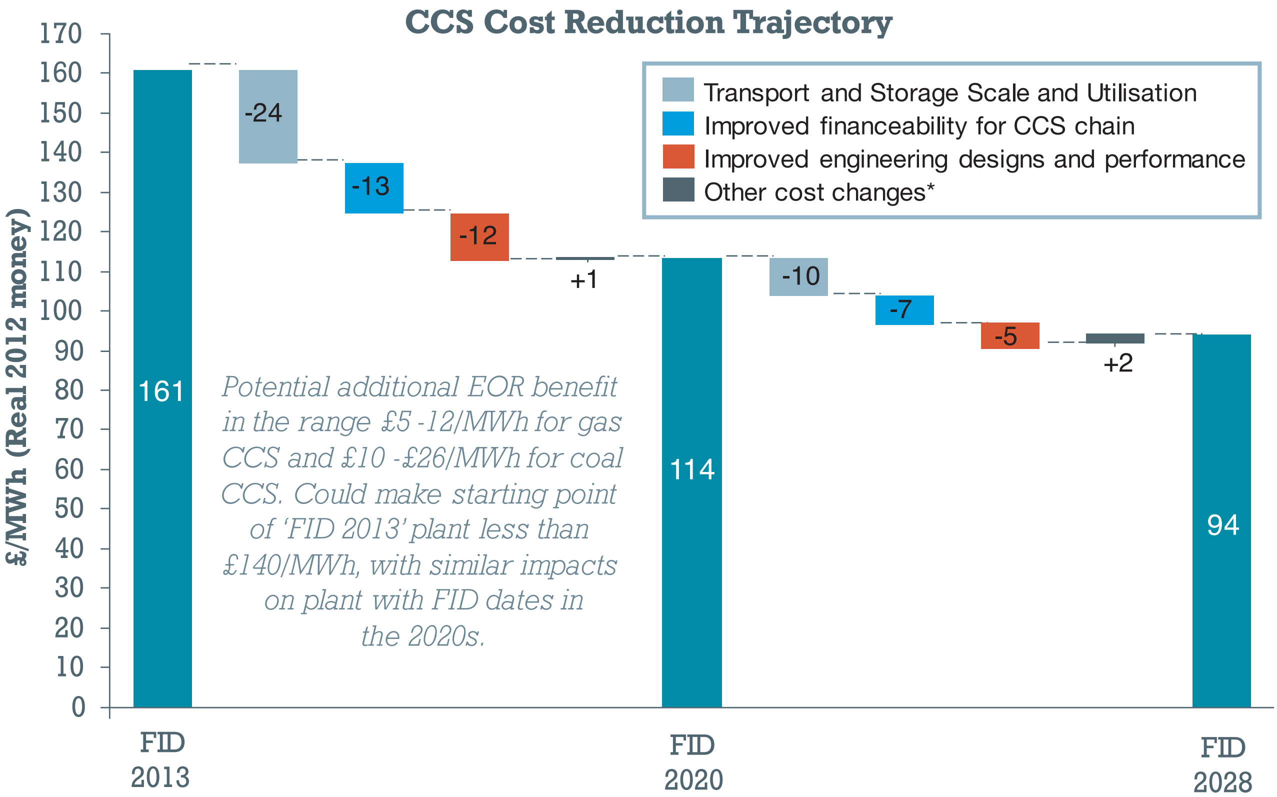
The cost reductions available in the early 2020s will be based on technologies that are already widely used at large scale, and that can be invested in with confidence and manageable risk. Further benefits from 'learning curve' effects, technology innovation, improved construction techniques, supply chain competition and the like will reduce costs further in the later 2020s.

These costs are potentially cheaper than alternative low-carbon generation technologies, without the system costs and drawbacks associated with supply intermittency or inflexibility.

## Components of cost reduction

Early CCS-equipped power generation projects commissioned before 2020, will have higher costs because of their smaller size; relatively short lifetime if built on existing power plants; single point-to-point (capture-to-storage) full-chain configuration; engineering prudence; and risk averse commercial and financing arrangements. The Task Force anticipates that the first set of projects may have costs in the range of £150-200/MWh.

CCS costs in the 2020s will also depend on the specifics of each particular project. However an indication of the relative significance of the five key factors listed above is given in the graph below. The key conclusion of the Task Force is based on the underlying analysis summarised in this chart. The Task Force is reassured in this conclusion by similarities across capture technologies and the commercial development of analogous technologies such as Flue Gas Desulphurisation and Combined Cycle Gas Power Plant.




**Note: Shows average costs across technologies. *E.G. Increasing $CO_2$ price, falling storage abandonment costs**

## The UK 'CCS Landscape'

The Task Force is confident that the measures outlined in the five areas above will have the effect of reducing the costs of electricity produced by CCS-equipped power plants by the early 2020s. However, this can only happen if these measures are taken against the background of a landscape in the UK that is favourable to the development of CCS projects.

The following are the key characteristics required of that 'CCS landscape':

### Credible long-term UK government policy commitment to CCS

i. A continued view within industry that the UK government remains serious about encouraging CCS projects, and will provide the policy and financial support (e.g. through CfDs) to enable their development.

ii. A publically stated aspiration that CCS will be deployed at scale in the early 2020s, provided it can be cost competitive with renewables, would be most helpful.

iii. Equipment suppliers and supply chains have sufficient confidence in the commitment to a steady roll-out of CCS that they can commit to invest their energies in this industry to reduce costs and improve performance.

iv. The planning framework – in all its guises, including national and local planning, seabed usage planning, etc – should have as its basis the presumption that CCS and associated infrastructure will be needed, rather than the view today that it may or may not be needed.

v. A coordinated plan for transport and storage, which allows for the development of infrastructure incrementally but with vision of the long-term.

vi. A suitable regulatory structure, and fiscal and policy framework to foster development of CCS at scale in the early 2020s.

vii. Clarity on the effective interpretation of the requirement that new gas plants be 'CCS Ready'.

viii. Continued government support for CCS R&D, to compliment investment from industry.

### Multiple operating full-chain CCS projects:

ix. Successful development of the projects coming out of the UK CCS Commercialisation Programme before 2020 (and earlier if possible), with a view to building on the storage and transport infrastructure that they create;

x. Ongoing offer to future CCS projects, built into the EMR, of a CfD sufficient to make good projects financeable.

xi. Commitment to and frameworks for learning and knowledge sharing from projects and research in the UK and globally.

### Continued engagement with the financial sector

xii. It is fundamentally important to maintain the current dialogue with the financial community so that its needs can be fed into policy development – responsibility for this engagement lies both with industry and with policy makers.

## Underlying sources of cost reduction

The Task Force has confidence in this conclusion because it has examined in some depth the effect of opportunities for cost savings in five aspects of CCS projects:

### Storage

- In order to finance full "economic-scale" CCS power stations, power station investors cannot be exposed to significant $CO_2$ storage risks. The transport and storage system must be very reliable, and its operating regime well matched to the intended operation of the power station.
- Uncertainty around the geological and operating behaviour of $CO_2$ storage sites means that reliable storage providers are likely to require access to more than one proven store, and to be capable of switching stores in order to provide back-up. This leads directly to the concept of proven 'storage hubs '.
- Through the correct configuration of the storage facilities in early projects it should be possible to structure a highly reliable storage service using storage hubs and multiple storage sites for follow on projects. This will make larger-scale generation and capture projects deliverable and financeable at costs in line with industry norms.
- A large part of the cost of $CO_2$ storage is set by the development costs of the surface facilities for the storage reservoir, that do not vary hugely with the rate of storage. Early projects with low $CO_2$ injection rates for storage will therefore incur high unit storage costs (unless they can share their storage).
- Storage will benefit significantly from scale. Multiple large generation plant supplying $CO_2$ to a hub will allow the storage development costs to be shared across large volumes of $CO_2$ stored.

The Task Force estimates that storage costs can be reduced from around £25/MWh in early projects to £5-10/MWh through investing in a $CO_2$ storage cluster supplying multiple $CO_2$ sites, that store volumes of around 5 million tonnes of $CO_2$ per annum. Lower costs per MWh could be seen in the longer-run, particular for gas based CCS, if higher volumes of $CO_2$ from multiple large capture plants feed into larger storage clusters.

### Transport

- A well designed pipeline network is a key enabler of the storage hub. It allows new storage sites to join the network over time; it allows multiple storage sites to operate together; and it allows operational switching between storage sites when necessary. The configuration of the transport system for early projects should take into account the likely future development of the $CO_2$ pipeline network, in order to reduce future costs.
- The unit costs of transporting $CO_2$ by pipeline decreases as scale increases. Both use and scale are important. This is supported by a key conclusion of the recent Mott MacDonald report, and endorsed by the Task Force, that leveraging early $CO_2$ infrastructure, if it designed correctly, can reduce the incremental cost of transport and storage substantially for later projects.
- $CO_2$ pipeline transport is a well-established technology and can be expected to have very high reliability, provided pumping reliability is given suitable attention.

The Task Force anticipates that transport costs could drop from around £21/MWh for early projects carrying 1-2 million tonnes of $CO_2$ p.a., to £5-10/MWh for large, well-used pipelines carrying 5-10 million tonnes of $CO_2$ p.a. Even lower costs per MWh could be seen in the longer-run, particular for gas based CCS, if still higher volumes of $CO_2$ from multiple large capture plants were feeding into an interconnected right-sized network.

### Generation and capture

- Early CCS projects developed in this decade are likely to be of modest size, in order to minimise risk across the full chain. Their levelised cost of electricity is therefore expected to be fairly high.

  Once CCS is established, significant reductions in electricity cost will be available through scaling up to plants sizes of around 1 GW, equivalent to unabated plants being installed elsewhere in the world.

The Task Force has confidence that full scale plants with $CO_2$ capture will be available, operable and financeable in the early 2020s, and therefore that these economies of scale will be realised.

- CCS power generation and capture technology, although not new, is not yet fully mature. Significant, progressive improvements, particularly in $CO_2$ capture capability, and reductions in the energy penalty of capture can be foreseen for the early 2020s.

  In addition costs can confidently be predicted to fall further thereafter, once learning from early plants installed across the world becomes available.

- Suppliers of CCS power generation and capture plant technology continue to be aggressive in developing their technology, and competition is substantial. If they continue to be confident that this market will grow, increasing supply chain scale and price competition will drive prices downwards.

  Cost reductions will also come from reduced redundancy, appropriate process integration and use of improved materials.

The Task Force estimates that generation and capture costs could drop from an average of around £116/MWh for early projects to £96/MWh for projects in the early 2020s. Significant further reductions in generation and capture costs are possible by the late 2020s and beyond through continued improvements in capture technology.

### Reduction in cost of capital / achieving affordable finance

Early UK CCS projects' cost of capital will reflect their novel nature, their limited size, a lack of industry track record, Government's requirement to limit its exposure and the commercial risks inherent in the CfD FiT structure.

For example:

- No commercial scale projects yet exist from which financiers can gain confidence in the model and the business;

- Storage risks and uncertainties can be perceived as significant until the store is operational and well proven;

- The CfD mechanism does not take account of the project-on-project risk along the CCS chain, with each part of the chain exposed to ongoing cost but no income if another part of the chain fails.

However, as the industry matures several developments are likely to reduce the cost of financing projects. In particular:

- De-risking the CCS chain, in particular through:
  - Providing a regulatory and policy structure that leads to financial security and insurance structures that allocate risk to those parties best able to manage them;
  - Creating an optimal contracting structure that balances contract standardisation to encourage financing with flexibility to adapt to project specific requirements;
  - Development of a storage solution that is 'proven' and demonstrably fit for purpose and robust to problems in any one store or well;
  - Building on the success of early projects to provide confidence in the operational performance of $CO_2$ capture equipment and the interaction with rest of the chain;

- Development of a suitable funding structure that caters for the full chain required by CCS projects, and incentivises them to provide flexible back-up to intermittent renewables in the future;

- Continued education and development of a critical mass of financial sector interest and involvement in CCS projects.

Estimating the individual contributions of each of these components is not straightforward, but informed members of the Task Force have suggested that the cost of capital (however raised) could fall from the high teens for early projects to around 10% or below by the early 2020s.

### $CO_2$-based Enhanced Oil Recovery ($CO_2$ EOR)

- $CO_2$ injection into oil fields is one method of recovering otherwise unrecoverable oil from mature oil fields, creating additional income to offset CCS costs, and deferring substantial decommissioning costs. The Central North Sea (CNS) oil province is mature with many fields set to close in the next decade.

  CCS and $CO_2$-based EOR fit together extremely well. Storage can be undertaken alongside EOR, and the revenue from additional oil production is a key reason for the development of many CCS projects in the US and Canada.

  A word of caution is needed when considering EOR, as not all Central North Sea fields are suitable for $CO_2$ EOR projects, technical and cost risk profiles are different from North America and there is no direct experience of offshore $CO_2$ EOR in the Central North Sea (CNS) or elsewhere. However, several oil companies are actively exploring the option of pursuing $CO_2$-based EOR on a number of fields in the CNS.

- Only a rough estimate can be made currently as to the value $CO_2$ may attract, if it were delivered, at pressure, to CNS oil field operators. Based on US experience this could well cover the cost of conventional $CO_2$ storage, and perhaps some of the transport costs as well. As a result this might decrease electricity costs by £5-12/MWh for gas CCS and £10-£26/MWh for coal CCS.

- It is the view of a number of informed Task Force members, and others who have been consulted, that $CO_2$ EOR investments will be actively pursued, and probably sanctioned on some fields, as soon as there is confidence that $CO_2$ is being delivered to the Central North Sea (CNS); and that this will reduce the costs of electricity from some of the power project investments that are expected to be built in the early 2020s.

- In addition to reducing the cost of $CO_2$ transport and storage, $CO_2$ EOR in the UKCS, could extend the productive life of some UK oilfields significantly. The resulting benefits could include tax revenues, employment, delayed decommissioning, and enhanced UK balance of payments.

### Other applications of CCS

Development of CCS in the power sector could unlock the opportunity for a wide range of applications of CCS with broader benefits for the UK economy and its low carbon transition. These are not taken into account in simple comparisons of Levelised Cost of Electricity (LCOE) figures during the 2020s and include:

- Industrial applications, enabling emissions reductions at low incremental costs, helping to safeguard key UK industries against decarbonisation requirements;

- Future CCS applications (including those with bio energy and gasification technologies) that can potentially enable the use of a wider portfolio of low carbon energy technologies encouraging greater efficiency and flexibility in meeting 2050 targets.


Image provided by Worley Parsons

# Introduction 1

In recent years, sustainability and security of supply objectives have become increasingly important for the energy sector. Energy policy and regulation objectives at European and UK levels have had to evolve in line with this change in direction. In its 2011 Electricity Market Reform white paper, the Department of Energy and Climate Change (DECC) summarised its policy objectives as:

- to ensure the future security of electricity supplies;
- to drive the decarbonisation of our electricity generation; and
- to minimise costs to the consumer.

The UK electricity generation sector is now on the brink of a radical transition to replace aging power plant capacity and to move to low carbon alternatives. Over the coming years, closure of existing coal, nuclear and gas plant will be driven by both the age of the existing generation fleet and by European environmental Directives. The requirement to replace this capacity could be turned into an advantageous infrastructure investment to enable continued use of fossil fuels in power and industry in a carbon-constrained economy.

Gas and coal-fuelled generation fitted with Carbon Capture and Storage (CCS) is, alongside renewables and nuclear, a core option for this replacement plant. The ultimate size of the CCS generation tranche will be determined by its cost competitiveness compared to alternatives and the timescale of which cost competitive plant is available.

The CCS Cost Reduction Task Force was set up by DECC to advise Government and industry on the potential for reducing costs so that CCS generation projects are financeable and competitive with other low carbon technologies in the early 2020s. This interim report provides a summary of the initial findings of the Task Force. A final report will follow by April 2013.

## 1.1 Role of CCS in UK electricity generation mix

Several potential generation technologies are available to help achieve the decarbonisation goals. Some have negligible carbon emissions and some have much lower emissions than available from current technology. The approximate carbon intensity of generation from selected technologies is shown in Table 1 below.

**Table 1 – Approximate emissions intensity of generation: Example technologies**

| Technology | Carbon intensity ($gCO_2$/kWh) |
|---|---|
| Conventional coal (unabated) | 750-900 |
| Conventional gas (CCGT) (unabated) | 350-380 |
| CCS coal | 80-150 |
| CCS gas | 30-70 |
| Dedicated biomass | Negligible net contribution |
| Nuclear, Wind, Marine | Negligible emissions |
| CCS biomass | Negative emissions |

Note: The numbers above reflect emissions at the point of generation. Lifecycle emission analysis, including any requirement for additional ‘back-up’ generation for intermittent generation, would show a higher emissions intensity.

The prospects and timescales for deployment of low carbon generation vary for different types of technology. However, given the rates at which new low-carbon plant can be commissioned, and the attendant risks associated with all technologies, it is essential that a complementary mixture of technologies is deployed. Early deployment of coal- and/or gas-fuelled CCS will help to mitigate technical and economic uncertainty and will increase the likely contribution from these technologies in the future – this will be particularly helpful in progressing towards the additional decarbonisation required after 2020.

One peculiar aspect of wind power generation is that, being at the mercy of the weather systems passing through the UK, output will be highly variable over time. Over the next decade, the main new technology built to meet renewables and decarbonisation targets in the UK is likely to be wind generation, both onshore and offshore.

Inevitably the intermittency of this new wind generation capacity will create additional challenges for the electricity market and system operation, as conventional generation has to be available to take over when there is little wind generation, and switched off when there is a lot of wind generation. There are therefore significant network management benefits in the longer-term to introducing alternative, potentially flexible, sources of low-carbon electricity such as abated coal and gas alongside intermittent renewable generation. By 'flexible' generation, we mean power stations whose output can be ramped up or ramped down in order to compensate for fluctuations in the power output from wind generators. Such plant flexibility is likely to be valuable even if it is only required in a relatively small number of time periods.

Fossil fuel generation with CCS is potentially able to operate in a flexible mode, increasing generation at times of high demand/low wind output and decreasing generation, even switching off, at times when it is not required. It therefore has the potential to provide much needed flexibility to the system and help avoid curtailment of wind generation.

## 1.2 Other opportunities and benefits associated with CCS

The benefits of the CCS Commercialisation Programme can extend well beyond the narrow confines of electricity generation. For example, CCS is an essential route to reducing carbon emissions for a number of UK industries; and the availability of transport and storage infrastructure will be critical to underpinning their economic health, and even their continued presence in the UK, beyond the early 2020s.

Furthermore, some CCS technologies under consideration for power applications involve the production of hydrogen in bulk, providing the opportunity to also decarbonise smaller CHP installations, provide feedstock for industry and, in the longer term, the opportunity to provide low carbon transport with reduced dependence on oil and also to enable partial decarbonisation of space heating. Availability of low carbon electricity production using CCS, can also promote fuel switching to electricity from gas, coal or oil for transport and heating.

There are also wider economic benefits to CCS that have been previously discussed by both DECC[1] and the Scottish Executive[2]. The Technology Innovation Needs Assessment (TINA)[3] stated that '*[CCS] Innovation could also help create a UK industry with the potential to contribute further economic value of £3-16bn to 2050.'* Additionally much valuable work has been undertaken by proponents of regional 'CCS clusters' in numerous locations around the UK. These benefits include:

- supporting regional development in:
  - regions where carbon capture can be deployed to large emitting power and industrial sources, helping to support the continued operation of those industries; and
  - regions where traditional offshore expertise can be used to develop $CO_2$ storage
- tens of thousands of new jobs in the CCS industry by 2030 as well as the protection of existing jobs in vulnerable industries;
- value creation from exporting CCS expertise to other geographical regions;
- long-term infrastructure development creating construction jobs as well as laying down valuable long-term strategic assets for the UK economy; and
- additional treasury revenue from increased taxation income where $CO_2$ EOR allows further oil reserves to be exploited.

## 1.3 Composition of the Task Force

The CCS Cost Reduction Task Force was set up by DECC to advise government and industry. The Task Force comprises around 25 members, selected from the engineering, hydrocarbon, finance, project developer and academic sectors. A full list of Task Force members and the terms of reference of the Task Force can be found in Annex B.2.

## 1.4 Approach

### Task Force methodology

The CCS Cost Reduction Task Force was established by DECC as part of the actions arising from the CCS Roadmap and is chaired by Dr Jeff Chapman, CEO of the CCSA and project managed by The Crown Estate. Three workstreams were established covering key potential areas of cost

[1] http://tinyurl.com/bsf4g9q
[2] http://tinyurl.com/5sgbgsu
[3] http://tinyurl.com/bsg65wb

reduction with 'workstream champions' nominated as experts in the field to lead those discussions:

- Planning and Infrastructure: Mike Saunders (represented by Alastair Rennie), AMEC
- Commercial and Financial: Allan Baker, Societe Generale
- Generation and Capture: Leigh Hackett (represented by Thomas Stringer), Alstom

Task Force members were given the opportunity to:

- take part in a series of workshops in each workstream;
- provide written response to a questionnaire seeking detailed cost reduction opportunities and the impact each would have on a levelised cost of energy (LCOE) for CCS equipped $CO_2$ emitters; and
- provide detailed input via a one-to-one discussion / interview session.

The overall process was facilitated by Pöyry with additional key experts not included in the original task force also consulted where it was felt they could provide significant expert knowledge in particular areas.

The key conclusions from this process were then discussed by the entire Task Force with individual chapters of the report reviewed by workstream champions. Finally, the overall document was assessed by a core team of Task Force members and agreed to broadly reflect Task Force opinion (recognising the range of views on many subjects).

### Modelling approach

Pöyry reviewed the model used in the DECC sponsored report by Mott MacDonald on potential cost reductions in CCS in the power sector[4]. Pöyry used the same general methodology and have taken Mott MacDonald data as a base for assumptions wherever possible. The model inputs were reviewed by the Task Force to establish a baseline from which to measure cost saving potential. This baseline is taken as a starting point when discussing cost reduction opportunities, and their impacts, within this report.

Cost savings for all four technology configurations covered in the Mott MacDonald report were examined:

- Post-combustion coal CCS;
- Post-combustion gas CCS;
- Oxy-combustion coal CCS; and
- Pre-combustion coal also known as Integrated Gasification Combined Cycle (IGCC) with CCS.

In places we refer to the technologies individually but we often show the average cost level across all technologies to simplify the message. Despite the differences in cost profile, the process has shown that the importance and magnitude of cost saving opportunities is broadly similar between the different technologies.

It should be recognised that:

- quantification of cost savings is difficult but the findings of this report appear broadly consistent with Mott MacDonald's analysis and findings in other similar studies once study-specific assumption have been accounted for; and
- forwardlooking cost analysis is subject to uncertainty and there is potentially more work that can be done to provide further clarity on the modelled outputs and overall cost levels.

**What this report IS**

This report is a representation of the opinion of the Task Force members on the opportunities for reducing the costs of CCS in power generation and what impact the delivery of those options may have on the agreed baseline referred to above. The report broadly references a single LCOE path; however this path is for discussion purposes only and is used to highlight the degree of impact potential cost reduction opportunities may have on the overall LCOE of CCS equipped $CO_2$ emitters.

**What this report IS NOT**

This report is not a detailed model or representation of CCS project costs. It is also not a list of actions that have been assigned to industry, government or any other stakeholder. The report presents cost reduction opportunities. Further analysis is required to determine exact impacts and costs and agreement is required as to who may undertake identified candidate actions if and when they are adopted.

[4] Potential cost reductions in CCS in the power sector, Discussion Paper, May 2012 http://tinyurl.com/c3cj9e8

Image provided by Worley Parsons

# Creating a favourable landscape for CCS in the UK by the early 2020s

# 2

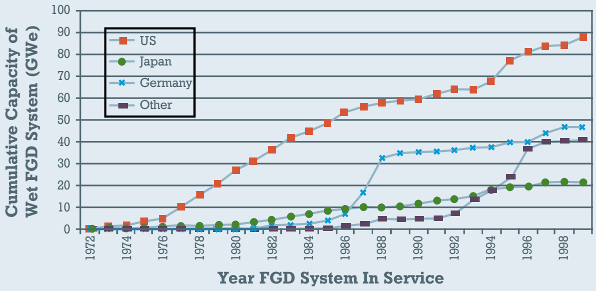
Like other technologies at an early stage of deployment CCS equipped power stations will have many opportunities for cost reductions as the deployment of the technology gathers pace.

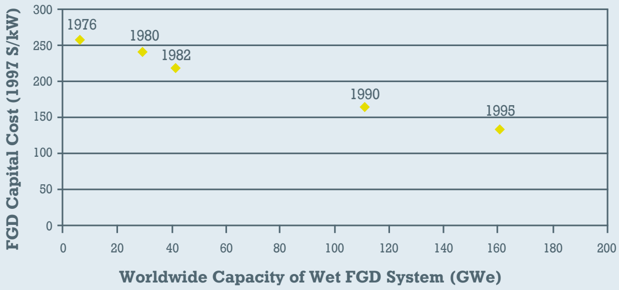
## Experience curves in a parallel technology: Flue Gas Desulphurisation (FGD)

Parallels can be drawn between the development of carbon capture and other emissions control technologies. This example is taken from a 2004 paper 'Experience curves for power plant emission control technologies' by E S Rubin et al.

From the 1970's onwards progressively more stringent controls have been introduced in the US, Japan and Europe over sulphur emissions from power generation. Historically this has been most relevant to coal-fired power plants. The increasingly strict emissions limits have led to the widespread adoption of post-combustion control systems of sulphur emissions, otherwise known as FGD. The most prevalent of these is a 'wet' FGD system employing limestone or lime as a chemical reagent.

If we can compare the capital cost of contemporaneous FGD systems (in this case fitted to a 500MWe coal plant, 3.5% sulphur coal with 90% $SO_2$ removal) to the worldwide installed base of FGD we can extract the 'experience curve' for FGD, showing the relationship between technology cost and installed capacity.



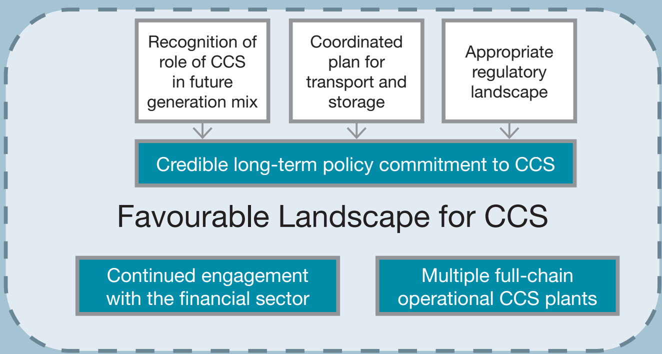




We can see that FGD costs exhibit significant declines over time. The view is that the costs reductions were largely the result of continued R&D activity although it is noted that competition between FGD vendors may also have contributed.

These experience curves are consistent with a large body of literature which examines a range of technologies.

However, cost reduction will only take place if a conducive 'landscape' engenders the transition from the early projects to a situation in which the application of CCS is viewed as 'conventional' as CCGTs (or FGD systems – see box) are now. If such a landscape evolves then many of the cost saving measures will manifest themselves as a function of installed capacity, as commercial market drivers drive industry toward cost saving measures.

The key elements of such a landscape are described below.



## 2.1 A credible long-term policy commitment

Although the CCS industry is committed to continuing to play an active role in policy development, many of the most critical decisions to put in place the correct fundamental drivers are in the hands of policymakers. If the right conditions are created, then the Task Force firmly believes that CCS will be able to compete with other sources of low carbon generation. These key conditions include:

- recognition of the role of CCS in the future generation mix;
- working with industry to facilitate coordinated deployment of transport and storage infrastructure; and
- ensuring the regulatory landscape is fit for purpose and does not unintentionally block CCS projects.

We now discuss each of these in more detail.

### 2.1.1 Recognition of the role of CCS in the future generation mix

The Task Force recognises recent positive statements made by the government about the future role of CCS, as well as the funds made available through the CCS Commercialisation Programme. Nevertheless, some ambiguity remains in terms of the long-term pathways for decarbonising the UK economy, and for roll-out of CCS in particular. Making large-scale CCS power generation explicitly part of energy mix plans, provided it can be competitive with renewables, would help to resolve this uncertainty. It would also be helpful if the government were to recognise explicitly the potential cost-effectiveness of CCS as part of emissions reduction and need for fossil fuels to back-up intermittent wind and loss of current nuclear fleet.

In order that equipment suppliers, project developers, financiers and other industry participants can make firm commitments to developing CCS in the UK, confidence in the long-term future of the industry is needed. In particular the development of the CCS supply chain, will require a perception that the UK will be undertaking a 'steady-roll out of CCS'. This will create an ongoing market for related products and services, without large boom and bust cycles of investment.

This recognition of the need for CCS, and the continuing need for CCS must also be present in the planning framework in all its guises, including national and local planning, and seabed usage planning. The planning and policy statements that influence those planning decisions, should have as their basis the presumption that CCS and associated infrastructure will be needed, rather than the view today that it may or may not be needed.

**Agreed Action: Development of CCS would benefit from a future vision/plan that has an assumption that coal and gas CCS will be needed in the UK, rather than that CCS might be needed in the UK.**

**Agreed Action: Development of CCS could benefit from a planning and consenting framework that has an assumption that CCS will be needed, rather than that CCS might be needed.**

### 2.1.2 Coordinated plan for transport and storage

The high-upfront costs of pipeline and storage infrastructure and the known large potential benefits from developing an optimal network of transport and storage suggest that potential cost savings could be realised if infrastructure is developed incrementally, but with a vision of the long-term design.

Transport and storage developments are also linked, as a well-designed pipeline network will also be a key enabler of storage hubs. So new storage sites will be able to join the network over time; multiple storage sites will operate together; and operational switching between storage sites will be simpler to execute when operational factors at any individual store require it to reduce capacity.

The Task Force believes that:

- Some form of long-term visibility of infrastructure plans would help project developers to plan suitably sized and located capture/storage sites. It is not yet clear whether this should extend as far as a centrally coordinated approach, or just an open and collaborative approach amongst project developers; and
- It would be advantageous if national planning framework/guidelines could be used to fast track consenting for storage and pipeline infrastructure.

It is currently unclear how much central planning is required to create a low-cost robust pipeline and storage network in the early 2020s and how much it is really a later stage issue.

**Agreed Action: Undertake activities to develop an optimal strategy for locating fossil power plants for $CO_2$ capture, to optimise the transport of fuel, electricity, water and $CO_2$ across the UK.**

### 2.1.3 Appropriate regulatory landscape

The complex nature of CCS projects, with the likelihood of most of them having different companies involved in each of the capture, transport and storage elements, will require a unique approach to regulation in general and funding mechanisms in particular. Some projects are likely to develop as end-to-end CCS chains;others are more likely to form or join clusters. Different elements of the chain may require different regulatory treatments. Some projects may include using the $CO_2$ for Enhanced Oil Recovery (EOR);

others will be simple storage. Regulations will have to be designed in a way that they retain their underlying drivers while also offering sufficient flexibility for a wide variety of project schemes.

More specifically, it is important that CCS is not artificially disadvantaged by the structure of funding mechanisms. There is some doubt within the Task Force whether the current EMR proposals will be fit for purpose for commercial scale CCS projects, and many members believe that unnecessary risks could unintentionally be introduced. The Task Force's views on funding mechanisms for projects reaching final investment decision in the early 2020s are discussed in detail in Section 5.2; it is also important that there is recognition that the unique features of CCS may necessitate a different treatment to other low-carbon generation in the next few years (i.e. at early stages of deployment).

Apart from the form of any support arrangements, it will also be important that Government can confirm that sufficient funds will be available to meet CCS and other low-carbon commitments, providing clarity around any funding limits applicable under the Levy Control Framework.

Industry and Government are already collaborating successfully on many areas of R&D in relation to CCS. The R&D requirement from both industry and Government is ongoing to deliver low-cost CCS in the early 2020s and to keep costs on a continued downward trajectory.

There has also been discussion in the Task Force that additional clarity on the effective interpretation of the requirement that new gas plants be 'CCS Ready' would be beneficial. As much of the infrastructure required for $CO_2$ transport and storage will need to be built with vision of the long-term, the potential future retrofit of gas plants with CCS could have a significant influence over shorter-term decisions for CCS infrastructure development.

Finally, the Task Force notes that excessively burdensome or overly prescriptive regulation is likely to stifle innovative solutions, and should be avoided.

## 2.2 Operational CCS plants

Demonstration of a variety of technologies and storage types/locations will be required to enable a full range of cost reductions to be realised in the 2020s and beyond. The Task Force considers that, for any given project, approximately three years of successful operation is required for equipment suppliers and operators to learn for the next wave of projects. This implies that in order for cost reductions to be achieved by the early 2020s a small number of projects must be deployed within the next five years.

The Task Force strongly supports the aims of the Government's Commercialisation Programme, and believes that this action will have the potential to kick-start a first wave of CCS projects in the UK. Delivery of this programme will be essential if the cost reduction opportunities outlined in this report are to be realised, as it can demonstrate that both the technical and commercial aspects of CCS are realisable (within each component in combination across the full chain). It will also raise public and investor confidence in what is still seen as a novel technology by those outside the industry.

A key aspect of the CCS Commercialisation Programme is to develop practical experience of the consenting and development process, which should in turn lower certain regulatory risks – not least, clarification around the long-term liabilities for $CO_2$ held in storage sites.

The Task Force also notes that CCS projects outside the UK have potential to provide useful information and experience that could be leveraged within the UK. Learning from other projects in Europe and beyond will be valuable and should be pursued wherever possible. Nevertheless, to stimulate development of supply chains and establish consenting processes a small number of projects will be required within the UK. These should have a track record of successful stakeholder engagement programmes; thiswill help to avoid public acceptance concerns that would make planning more difficult.

## 2.3 Continued engagement with financial sector

Financing early commercial CCS projects is likely to be far more complicated than conventional power projects, because new financial structures need to be developed, and appropriate sources of funds brought in. Subject to suitable revenue streams being in place, some parts of the CCS chain may be financeable through conventional project financing; others will require a more tailored approach. In particular, project finance for the storage sector is unlikely to be forthcoming without proven revenue certainty, which in turn will be extremely difficult for early projects.

These challenges dictate that the financial sector is able to adequately understand and assess the value drivers and risks associated with CCS projects. Conversely, policy must account for the real-world imperatives faced by banks and others involved in financing CCS projects.

The Task Force notes that, realistically, there is likely to be limited active interest from commercial banks and other finance providers now, because of the lead times in developing commercial scale CCS projects. Nevertheless, it is fundamentally important to maintain the current dialogue with the financial community so that its needs can be fed into policy development. Failure to take account of these needs would be to risk the potential for 'bankable projects' in the 2020s.

The nature of this engagement is likely to require that a core number of experts from the financial community remain involved in the debate – and that these individuals are drawn not only from the banking sector, but also the insurance industry and other related areas. The responsibility for this engagement lies both with industry and with policy makers.

## 2.4 Key conclusions

The landscape described above will not, by itself, guarantee that costs of CCS projects in the early 2020s can be reduced to a satisfactory level. However, it will enable a wide range of costreducing actions to be pursued. The most tangible ones can be grouped into three areas corresponding to the Task Force workstreams:

- **Planning and infrastructure developments** – focused on maximising transport and storage economies of scale.
- **Generation and capture technology development** through improved engineering designs and performance; and
- **Commercial and financial arrangement evolution** to achieve affordable finance for the CCS chain.

These three broad areas are discussed in the following sections of this report.

# Maximising transport and storage economies of scale and system efficiencies

# 3

Virtually all of the CCS projects proposed in the UK to date are based on isolated full chain schemes in which a single power station is connected via a single dedicated $CO_2$ pipeline to a storage site in the UK Continental Shelf (UKCS), generally a depleted oil and gas field (DOGF) or else a saline aquifer. Pipeline and storage costs in these early projects will be significant contributors to the LCOE with costs in the region of £30-50/MWh.

In the context of the landscape actions discussed in Section 2, a variety of cost saving routes were identified by the CRTF. This section will present the main findings for costs reductions from the Transport and Infrastructure workstream.

## 3.1 Achieving optimal scale in transport and storage

### Storage

A large part of the cost of $CO_2$ storage is associated with the development costs of the storage reservoir, which are incurred even for quite low volumes of $CO_2$ injection. As higher volumes of $CO_2$ are injected in a particular site, additional costs will be incurred (primarily more wells and additional monitoring) but the percentage cost increase will be small in comparison to the overall increase in volumes. Early projects with lower CO2 volumes for storage will therefore incur higher unit storage costs (unless they can share their storage) but, as with transport, storage will benefit significantly from scale.

The Task Force estimates that storage costs can be reduced from around £25/MWh in early projects to £5-10/MWh by investing in a $CO_2$ hub (or cluster), supplying multiple $CO_2$ sites, storing $CO_2$ volumes of around 5 million tonnes of $CO_2$ per annum. Lower per MWh costs could be seen in the longer run, particularly for gas-based CCS, if higher volumes of $CO_2$ from multiple large capture plants were feeding into larger storage clusters.

In addition, if a storage cluster is developed so that there are multiple storage types and geologies, the reliability of the storage will be increased so lowering risks for developers in each element of the chain. This will be a key step in making full economic-scale generation and capture projects deliverable and financeable at costs in line with industry norms (see Section 3.2 and 5.1.3)[5].

For such storage hubs to be in development by the early 2020s, the Task Force believes that the current CCS Commercialisation Programme would need to deliver a number of projects that are structured to deliver a high reliability storage service to follow on projects that aim to operate in the early 2020s.

**Agreed Action: Consider how to ensure contracts and licences can be structured flexibly enough to allow $CO_2$ to be injected into alternative stores by agreement between storage owners.**

### Transport

The unit cost of transporting $CO_2$ has the potential to decrease significantly at higher volumes because the costs of constructing and installing pipelines grow at a much slower rate than volumes they can transport. In an ideal world a single, very high capacity (over 10mt/year), source committing to fully use a pipeline for 25 to 40 years would give a low transport cost. However, the utilisation factor is also important because a large pipeline that has spare capacity for much of its lifespan would have higher unit transport costs than a smaller one that is full year on year.

Additional fundamental drivers of transport costs are pipeline distance, the crossing terrain (particularly onshore) and planning costs. It is therefore apparent that the lowest cost transport network will be one that:

- transports large amounts of $CO_2$ in appropriately sized pipelines;
- is cognisant of sizing of trunk line sections and feeder line sections to ensure high use for the maximum period of the asset lifetime (average flow compared to maximum flow);
- minimises the distance $CO_2$ is transported (factored for terrain, shoreline crossings and planning constraints) restricted by decisions on the capture and storage sites; and
- minimises the need for building additional pipelines that would incur significant planning costs.

The Task Force anticipates that transport costs could drop from £18-23/MWh for early projects carrying 1-2 million tonnes of $CO_2$ p.a., to £5-10/MWh for large, full pipelines carrying 5-10 million tonnes of $CO_2$ p.a. Even lower per MWh costs could be seen in the longer-run, particular for gas based CCS, if even still higher volumes of $CO_2$ from multiple large capture plants were feeding into an interconnected right-sized network.

[5] Development of storage clusters has been discussed in some depth by Task Force members in the past in previous reports such as the Central North Sea – CO2 Storage Hub report released in September 2012.

This is supported by a key conclusion of the recent Mott MacDonald report, and endorsed by the Task Force, that leveraging early $CO_2$ infrastructure, if it is designed correctly, can reduce the incremental cost of transport and storage substantially for later projects.

**Agreed Action: Ensure that configuration of the transport and storage system for early projects takes into account likely future developments of $CO_2$ storage hubs and associated pipeline networks, to minimise long-run average costs.**

## 3.2 Characterisation of storage

Site selection for storage is important to access low cost, low risk storage. Assessment of each particular storage site will depend on a number of factors:

- Geographical location of storage site;
- Timing of storage site availability (generally due to other activities at the site);
- Data availability, particularly for existing wells and seismic data, allowing development of a geological model and parameters for the rock and fluid properties; and
- Being able to build a sufficiently good storage reservoir model.

This then enables key features such as injectivity, well design, and capacity to be used with some confidence level in the business case for investment.

To some extent necessary data on potential storage sites is contained in public and private databases; this is particularly the case for depleted oil and gas fields. For other reservoir types, generally saline aquifers, significantly more characterisation work will be required (although it should be recognised that within these broad categories of storage type the level of data for individual sites can vary greatly).

Collecting and having access to reliable data on storage opportunities will:

- create additional confidence in general storage solutions, minimising the risk perception for $CO_2$ storage:
  - Enable the development of diverse storage options, so that (collectively) their storage capacity is 'bankable' which ultimately requires several proven stores that are equally accessible. This is referred to as a storage hub.
  - Financial institutions currently regard storage as the least well known element of the chain and public perception of storage is mixed – this is part of a general de-risking of the CCS chain as described in 3.1.3.
- maximise the ability of firms to select the most advantageous storage sites, reducing capital and operational costs, and the probability of selecting inappropriate sites.
  - Although the geoscience and CCS communities are both confident of overall storage potential in the North Sea, the suitability (with regard to 'average' injectivity and storable $CO_2$ volume) of individual sites is necessarily uncertain.
  - To some extent a site will be more favourable if there are other good potential injection sites nearby.
- attract a wider range of players into the storage business in the long-run, bringing competition and lowering costs.

However, there are significant costs involved in characterising storage. Key steps are typically: a desktop study of seismic and well data; the collection of new seismic data; drilling new data collection wells; drilling test injection wells and injecting water/$CO_2$.

The step-up in cost at each sequential stage of characterisation at an individual store is significant (up to 10s of £m at the top end). Though not as speculative as drilling for hydrocarbons it must be assumed that some test wells will prove that a storage formation is not suitable. Once a formation is selected for investment and is proven, it will be natural that additional capacity will be sought in the same formation and/or nearby because of better local knowledge, to minimise the risk of new negative information. Such new sites will then benefit from lower incremental transport and $CO_2$ test injection costs.

Given the likely high costs, one potential development model to manage the costs and risks for an individual hub would be as follows:

- Target the nearest potential hub location that has diverse storage options.
- Without new drilling, characterise options in the area, (using existing cores, seismic and regional data) select the lowest risk option for storage in the context of the business case for the hub.
- Where there is an available depleted oil and gas (DOGF) storage as an early, already highly characterised, store it may be possible to avoid new drilling as at worst it may take the full $CO_2$ output of a single CCS project for only a limited number of years;
- Provide transport; use what capacity is available with existing pipelines or build a right sized hub trunk line connection.

- After a period of first injection characterise and test nearby opportunities in additional DOGF storage and/or saline aquifer storage to increase the storage capacity and flexibility of the hub. This is important as reduces the risk of unexpected problems with the first store. Hub spoke pipes are sized to suit the incremental capacity.

- Develop spoke pipelines to $CO_2$ EOR opportunities as fields become available to create additional value for the $CO_2$ hub and lower the cost of $CO_2$ storage (see Section 6.2).

The commercial arrangements could become complex as store operators offset their service obligations by options to store with other operators, but being able to do that will benefit emitters, who would otherwise require multiple storage off take contracts to ensure their CCS asset utilisation.

The natural advantages from developing additional storage sites at a hub or next to an existing $CO_2$ pipeline mean that there are natural economic drivers to further expand it (as pipeline savings from shorter distances are likely to be outweighed by confidence of a proven storage reservoir). However, there may be significant value to establishing a new hub if there is very large storage capacity and it lowers storage and transport costs in the long run.

Because of the risks involved, entirely new hubs will only be developed if there is a decent prospect of a step change in cost reduction.. Gaining access to the lower potential costs is one of the reasons why a strategic plan for transport and storage would make sense.

It should be noted that the UK is endowed with an enormous strategic asset in relation to the storage capacity in the UKCS and that the rights for carbon dioxide storage are vested in The Crown Estate.

**Agreed Action: Examine the options for characterisation of storage areas for $CO_2$ in the UKCS and recommend a way forward. The objective is to make storage bankable from a commercial and technical perspective, including via the reduction of 'exploration' risk premium.**

## 3.3 Regulatory framework and funding mechanism

Both the Task Force and the UK CCS Roadmap recognise that creating the right regulatory framework for CCS is crucial for the deployment of CCS. However, the lack of CCS projects in the UK means there is also a lack of experience in regulatory agencies and commercial entities of how regulatory systems would apply to CCS infrastructure. This increases the risk for the establishment of early CCS projects, driving up the costs of development.

A key aspect of the CCS Commercialisation Programme is to develop practical experience of the consenting and development process, which should in turn remove certain regulatory risks. Not least is clarification of the long-term liabilities for $CO_2$ held in storage sites.

Long-term liabilities associated with storage of $CO_2$ for very long timescales will need to be addressed in order for projects to be financeable. Commercial entities will find it extremely difficult to carry large and open-ended liabilities on their balance sheets, and will look to Government to take over responsibility at some point. The Task Force welcomes the progress on these issues that has been made as part of the Commercialisation Programme, but believes a robust and enduring solution will need to be put in place that is suitable for all projects, through the 2020s and beyond. This learning from operational projects forms part of our landscape as described in Section 2.

In the longer-term, several concerns were raised by the Task Force about how the regulation and funding mechanisms for $CO_2$ transport and storage may change over time as the industry matures.

There is a wide range of options available for the future of the industry, in particular the level and extent of regulation that will be used in transport and storage sectors:

- Light-touch regulation whereby development of the transport and storage industry is market led with standard third-party access requirements in line with current pipeline infrastructure; or

- Heavier regulation, such as defining a monopoly provider of transport and storage infrastructure in a region, and then applying regulation on the allowable rate of return.

Although developing a highly regulated sector would require significant regulatory changes before 2020, a stable regulatory framework in the 2020s will be critical for the deployment of low cost CCS. The key principles governing the future regulation should be established as early as possible to reduce regulatory risks for participants.

The regulations are in place for third party access, but the guidance for this, particularly for storage access, has not yet been issued. Though third party access for storage is quite difficult to describe, some guiding principles can be defined. For example allowing cost recovery and enabling storage owners to agree options with other storage in hubs will help ensure that long-term emitters (who can access transport and agree a storage contract with a store owner) will be able to store their $CO_2$.

The funding mechanism that is applied to the transport and storage of $CO_2$ could also have a large impact on the costs of deployment. These options were discussed as part of

[6] http://www.thecrownestate.co.uk/energy/carbon-capture-and-storage/

the Planning and Infrastructure workstream as well as in the Commercial and Finance workstream. These funding options and the impact they have on costs is discussed further in Section 5.2.

**Agreed Action: Assess what future development of the policy and regulatory framework is required to deliver CCS projects.**

## 3.4 Conclusions: storage and transport cost reduction opportunities

All the routes described above effectively facilitate access to two general cost reduction mechanisms: reduced capex and reduced opex in both storage and transport sectors.

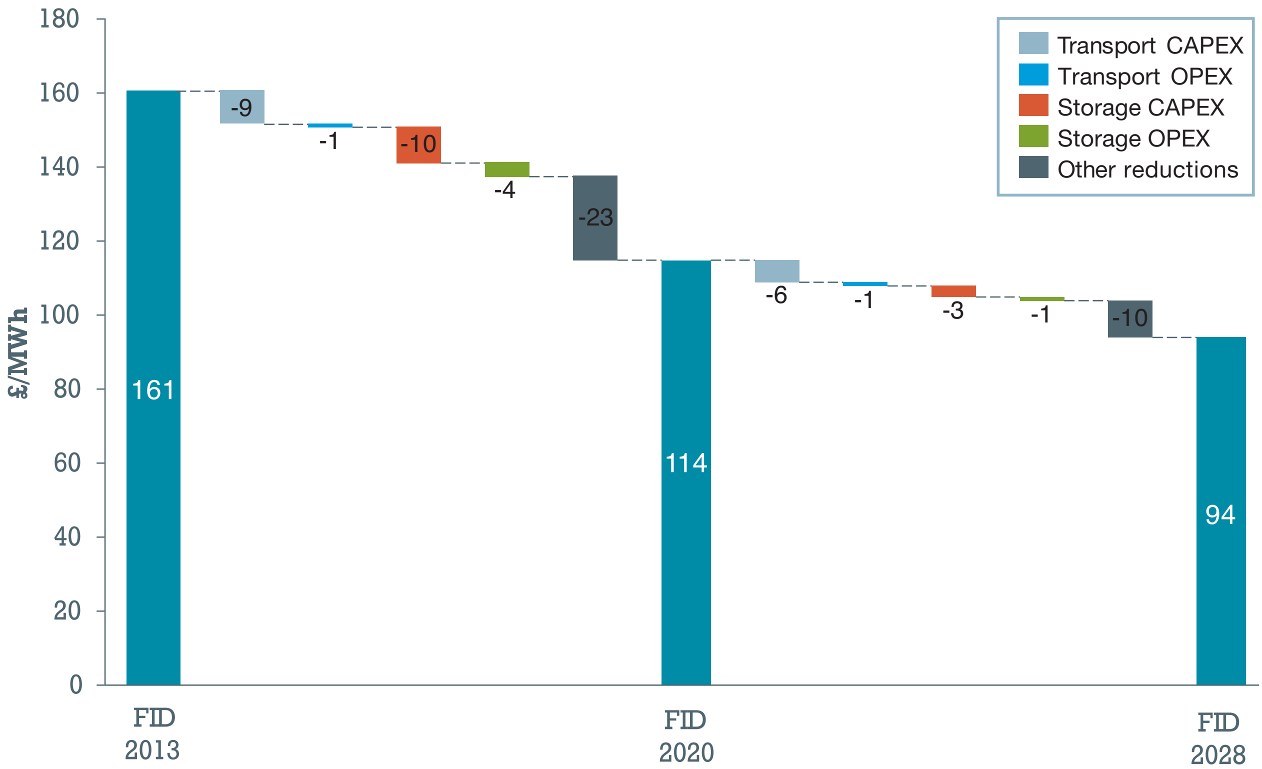
The potential for cost reduction that falls within these mechanisms is summarised in Figure 1. The 'Other reductions' category includes the cost reduction measures achievable by the other cost reduction pathways in this report. These are discussed in Chapters 4 and 5 below but it should be noted that the Commercial and Financial workstream also included measures that impacted transport and storage costs.

The Task Force anticipates that there is the potential for transport costs to drop from £18-23/MWh for early projects to £5-10/MWh for FID 2020 plants and £1-3MWh for plant reaching FID in the late 2020s. Additionally there is the potential for storage costs to drop from £22-26/MWh for early projects to £5-10/MWh for FID 2020 plants and £2-5/MWh for plant reaching FID in the late 2020s. A breakdown of modelling assumptions and costs is provided in Annex A.

The underlying driver of cost reductions in both transport and storage is the ability to facilitate increased throughput of $CO_2$ into the system (ultimately manifested by applying routes discussed in Section 3.1). Increasing the $CO_2$ throughput of the system incurs costs associated with the deployment of larger diameter pipes and longer pipe lengths (representing the facilitation of clusters); however, the increase in the equipment costs is significantly outweighed by cost savings associated with increased $CO_2$ throughput.

In the model, increased throughput is effected via an increase in pipe diameters. By FID 2020 pipe diameters have increased from 15" to 18" (coal plants) or from 10" to 15" (in the case of gas plants); this facilitates an increase in throughput from 2 to 4 mt/year and from 1 to 2 mt/year respectively.

Figure 1 – Potential cost reductions from maximising economies of scale and system efficiencies of transport and storage (real 2012 £/MWh)




**Notes:**
Diagram show technology average costs (i.e. average costs across all four technologies examined).
Results are presented on a £/MWh basis, the general pattern would be similar if presented in a £/tonne basis, however, future benefits would appear less favourable due to increased plant effciencies (and consequently a declining $CO_2$ capture rate).

By FID 2020, average onshore pipe length has also increased from 30 to 40 kilometres (we assume, in line with Mott MacDonald, that average offshore pipe length remains at 300km throughout the modelled period). These increases in throughput (and the pipeline diameters assumed) are in line with capture volumes from larger single CCS projects on power stations – it may be that larger pipelines are being developed (for future CO2 flows to feed into at a later date) but the potential positive impact of such a system is not included.

By FID 2028 the model assumes further increases in pipe diameter, reaching 36" (and assuming 15mt/year throughput) in all cases, representing increased economies of scale from clustering projects. However, a 36" pipe has the potential to transport more than 15mt/year at higher pressures; this means that there is the potential for even greater economies of scale (above those assumed in the modelling to 2028). The capex reduction mechanisms discussed above are also expected to bring down the opex of projects (as annual opex is assumed to be 2% of capex throughout the modelled period, as per Mott MacDonald assumptions), opex therefore declines in proportion with capex.

#### 3.4.1.1 Additional cost reductions in transport and storage

Additional reductions in transport and storage costs can be accessed through financial mechanisms (in particular, by improving the financing terms available, see Section 5); these mechanisms should thus ultimately be considered together. Such financial benefits can only be exploited by reducing risks, particularly those associated with storage and regulation. This is in part facilitated by the measures discussed in Sections 3.1, 3.2 and 3.3.

Image provided by Worley Parsons

# Improving generation and capture engineering designs and performance

# 4

CCS plant in general will have higher cost metrics than conventional thermal power stations because the process needs additional capital equipment to capture and compress the $CO_2$; additional energy is needed to run the separation and compression plant (thus affecting the net energy output of the plant); and additional operating expenses are incurred owing to consumption of solvents, chemical reagents, catalysts and formation of waste products.

Additional generation and capture costs for the first commercialisation phase projects suggests a range of costs from £35-46/MWh (after removing carbon cost impacts). However, there is clear scope to minimise the difference through lower:

- capital equipment costs;
- capture operating costs; and
- energy penalty (i.e. the difference between the net energy delivered to the grid in a CCS case and the net energy delivered to the grid in a non-CCS case7).

The main routes are described below.

## 4.1 Optimal scale of generation and capture unit size

Current sizes of demonstration plants (first generation technologies) range between 200 and 400MW. Early commercial CCS power projects developed in this decade are also likely to be of modest size, in order to minimise risk capital across the full chain in the first developments. The levelised cost of electricity from these plants is therefore expected to be fairly high. The CRTF suggests that early commercial phases should be in the 600 to 800MW range but also acknowledges that projects over 1000MW should also be considered at this stage.

Economies of scale can be captured by either scaling up the size or the number of units, a choice that is very much project specific. Once CCS is established, significant reductions in electricity cost will be made by scaling up to plants sizes to around 1 GW or more, equivalent to unabated plants being installed elsewhere in the world today. This will:

- improve efficiency in the base plant;
- lower capital costs and some operational costs at the base plant;
- allow additional economy of scale benefits in components of the capture units;
- allow additional economy of scale benefits in the transport and storage sectors (see Section 3.1).

To some extent 'the bigger the better' with regard to the unit costs of capture components, as potential economies of scale are regarded as significant. However, it should be noted that for several of the key equipment and systems required in a CCS plant, larger sizes are often not yet commercially available and, therefore, the currently available size 'breakpoints' will limit scaleability. With the widespread introduction of CCS projects, industry will have the incentive to push the limits on such equipment and develop larger and more cost-effective components. Examples of such equipment where economies of scale are expected to be significant include: air separation unit (ASU) cold boxes, air compressors (for ASUs), $CO_2$ compressors, pumps, heat exchangers, columns (distillation, absorbers, regenerators) and gasifiers. There are likely to be different optimal scales for different technologies but scale benefits on individual components could be of the order of 25% of capital costs for that particular component.

Although these larger sized components, once commercially available, ought to drive a lower capex for the CCS plant, there is likely to be a corresponding increase in single point failure risk. Likewise, unplanned outages of larger-sized components/units represent increased load losses and thus increased pressure on the grid. In this case, there will be a tendency toward potentially increasing contingency requirements and introducing limits to reasonable gains.

Even where there are limits to the scale of the component parts, there will be potential additional benefits from ordering more than one component from a single manufacturer. Benefits in the order of a 15% reduction in cost for a second component (compared to the first) are regarded as reasonable.

Over-capacity of critical components is often designed into a power train to ensure continuity of generation during outage: for example, additional solvent feed pumps or ASU modules. Larger plants with more critical units may still require only one back-up unit. These kinds of impacts are discussed in more detail in Section 4.2 below.

The Task Force believes that full scale plants with $CO_2$ capture can be available, operable and financeable in the early 2020s if the landscape described in Section 2 is in

[7] Many observers use the term "energy penalty" to describe the extra energy costs of the CCS process compared to conventional plant. For convenience we use this terminology in this report, although it should be recognised that many aspects of this are identical to the thermal efficiency of any plant i.e. that there are energy losses.

place. There is therefore strong confidence that economies of scale associated with power plant scale-up will be available in the early 2020s.

The suite of early phase pre-commercial CCS projects in the size range 200-400MW will provide industry with the incentive to push the existing technology envelopes and develop these offerings. Such projects, once operational will enable suitable testing opportunities and provide data on performance and availability that can be used to provide the guarantees likely to be required to make CCS financeable.

**Agreed Action: Projects developed in the UK following those arising from the Commercialisation Programme should be of a size much closer to the full size unabated plants available, in order to capture the economies of scale that should then be available.**

## 4.2 Optimisation of early designs and reduction of engineering redundancies

In addition to the benefits of increased plant scale, some other costs associated with the first commercialisation phase projects are likely to fall during the second and third waves of projects without the need to assume technological advancements. Optimisation of processes, designs and a reduction in engineering redundancies has the potential to reduce capture costs significantly.

### Reduced developer/design contingency

As the first wave of CCS plants deliver operational experience (described in the landscape) and larger plants are developed, plant designs should remove certain types of redundancy and design margin. Alongside optimised construction strategy, this reduced contingency should reduce 'superfluous' costs.

Balanced against the cost advantages of lower margins/redundancy, will be a reduced level of availability, as the system will no longer contain such a high level of back-up. Designs can therefore be expected to optimise the 'availability versus redundancy' equation so that costs decrease and/or availability improves over time.

However, experience in other industries indicates that costs can actually increase from the first wave of projects to the second wave before then decreasing with further deployment. It is often the case that this cost increase is driven by overly strict performance standards on the technology in the early stages of commercial deployment. CCS can avoid this pitfall (and must if it is to deliver low cost in the early 2020s) by ensuring that:

- market support allows plant to operate at less than baseload without CCS without having a distorting impact on plant returns;
  - e.g. If you impose an 80% availability requirement on a plant which, in its first year, only manages 79% then it could lose all revenue whereas in a market situation it would only be marginally affected.
- policy allows plant to operate at least some of the time partially without CCS without unduly affecting the plant returns; and
  - lowering required capture rate for early years of operation.
- making sure that plant design margins and $CO_2$ quality standards are fit for purpose given the H&S implications.

It remains to be seen just how significant this process of reduced contingency can be as it will depend on the performance of the first commercial scale CCS projects, and future licensing and permitting requirements.

**Agreed Action: Ensure that the optimal balance between scale risk, equipment redundancy, design margins and required availability is achieved; including the requirement that any constraints (e.g. $CO_2$ specifications), design requirements (e.g. capture percentage limits) or performance objectives (e.g. minimisation of cost of electricity generation) are set with the intended and possible unintended consequences of these limits, clearly understood and agreed.**

### Better integration of capture unit into generation plant

We could expect to see engineering designs improve the level of heat integration between the capture unit and the generation plant. By utilising steam/heat at the optimum temperature level (i.e. using the lowest grade heat possible from the power plant) you can minimise the energy penalty associated with the capture system. However this must be balanced against:

- the disadvantage of reduced flexibility/availability, (over-integration may prevent effective operation in future market); and,
- the need for reliability as a fundamental prerequisite for effective integration reduces the speed with which integration can be progressed.

To some extent early projects will already be aiming to maximise integration while still maintaining flexibility and reliability, but the 'optimal' setup is uncertain and will depend on the evolution of the rest of the electricity market and other sources of value (see Section 6.2). Indeed, some Task Force members questioned whether or not early plant designs may already be too integrated. For this reason, although there is perceived potential for increased integration into the plant, the scope is regarded as limited by the early 2020s.

Benefits in capital cost optimisation can be achieved through smart 'physical' integration between the CCS plant and the power plant. This will be the case for a greenfield power plant with CCS which has considered the optimum layout of all physical components and minimising interfaces such as duct work, utility piping, electrical tie-ins, etc.

**Agreed Action: The benefits and downsides of integration should be examined from the experience of all early projects, worldwide, in order to incorporate this experience into future designs.**

## 4.3 Evolution of current capture technologies

**In general technological improvements will be a function of how many plants are deployed globally. Thus, the more plants in operation, the faster the evolution. On the other hand, if only a few plants are developed before 2020 the rate of technological advancement will be slow.**

**In general significant improvements are expected in existing capture technologies between now and the early 2020s. All technologies should continue to improve during the 2020s as roll-out continues, but over time we can expect the costs of these 'current generation' technologies to tend towards natural limits.**

### Capture process

There is a potential for current capture technologies to improve incrementally as experience grows between today and projects reaching FID in the early 2020s. These current capture technologies can be largely defined as:

- **Post-combustion:** Capturing $CO_2$ from the flue gas of a conventional gas or coal fired power plant using an absorption based process (utilising absorbents such as amines or ammonia);
- **Oxyfuel:** Coal is burned with oxygen (generated from an ASU) rather than air resulting in a flue gas containing $CO_2$ and water (no nitrogen). $CO_2$ is then captured from the resulting flue gas.
- **Pre-combustion:** Gas or coal is converted in a gasifier into a mixture of hydrogen, CO and $CO_2$ . In the case of power generation, the CO is further converted to $CO_2$ which is then captured from the resulting gas, generally using an absorption based technology. The remaining H2 rich gas is then burned in a gas turbine to generate power.

There are a number of specific technology improvements that are at pilot-stage or very close to pilot, and as such these represent opportunities for cost saving by the early 2020s timespan. These include:

- solvent (e.g. amine) improvements;
  - There have already been considerable improvements made in the last five years as technology providers have shifted from using standard solvents such as monoethanolamine (MEA) to more advanced solvents tailored for post-combustion capture. As much as a 25% improvement has been realised to date by many technology providers. Further improvements can be expected; however, as these will likely mean tailored chemical solvents, the cost and supply chain considerations need to be traded off against the potential energy benefits.
- alternative solvents (i.e. alternatives to amine) that fit within similar overall flowsheet;
- absorption process improvements such as improved internal heat integration, external heat integration and overall process optimisation;
- improvements in physical absorption processes used in pre-combustion based systems;
  - advances currently under way through the ETI technology programme;
- further improvements to IGCC as learning develops from the operational experience of IGCC projects worldwide;
- improvements in critical equipment performances such as column packing, heat exchangers and $CO_2$ compressors; and
- improvements in air separation technologies (process cycles optimised for oxy-combustion processes) resulting in low specific energy consumption.

There is a theoretical lower threshold to the level of energy consumption required to extract $CO_2$ using any of the above technologies. Some technologies will plateau earlier than others and it is currently unclear which technologies can go further than others in the necessary time-frame.

The Task Force believes that there is no current obvious technology or fuel winner for CCS and developing a market for CCS in the long run is the optimal way to drive improvements and lower costs.

The key question for each of these technologies is:

*What can we do to make improvement in this area happen? What will drive technological improvement?*

### Improvements in materials of construction

Optimisation of materials of construction utilised within the capture plants has the potential to lower capital costs. Potential cost saving measures by the early 2020s include:

- using cheaper material (including a reduced dependence on steel) as a better understanding of material robustness and corrosion resistance is gained through operational experience. Examples include:

 – using more concrete (in absorbers in particular) could save up to 30+% of cost can be saved on the absorber; and

 – using lower cost steel or polymers;

- the use of off-site fabrication for certain components that may be more cost-effective when large plants with multiple units are being constructed.

**Improvements in flexibility of power generation with CCS**

During the period between today and 2030, the UK's power grid is expected to evolve toward a greater percentage of renewable power generation (e.g. wind power). This evolution means that fossil power generation with CCS will need to be flexible in order to efficiently match the demands of the grid (see Section 1.1 and Section 2.1.1.)

It is expected that the current capture technologies will be capable of enabling a sufficiently flexible CCS installation. However, the exact capabilities of CCS power will vary based on the actual technology employed and will need to be further proven through the early phase projects. The current views on system capabilities can be summarised as follows:

- Post-combustion: Absorption based processes can be made to follow the load of the host power plant through the use of advanced control systems. A key factor will be the specifications imposed on the capture plant performance. If the $CO_2$ recovery rate can drop below 90% (for example) for a short period of time during the ramping period, then it should be quite straightforward to achieve rapid ramping rates.

- OxyFuel: Ramping an oxyfuel CCS process will require load following of the ASU as well as the back-end $CO_2$ purification system. While dynamic ramping can be achieved through advanced controls, an oxyfuel system offers a unique approach to reacting to load. During periods of low load from the grid, the power plant can remain at a constant load and the extra electricity used to generate liquid oxygen from the ASU, which is then stored. Then during periods of high electricity demand, the ASU can be turned down and the liquid oxygen used to supply $O_2$ to the process. In this way, the liquid oxygen serves as a form of energy storage.

- IGCC: Compared to a PC-Coal or NGCC plant, IGCC has a lower operational flexibility. While PC-Coal or NGCC plants have proven to reliably cycle down to low loads, the gasifiers associated with IGCC plants are best operated at a constant or near constant rate. However, flexibility can be achieved with an IGCC solution if there's an outlet for the syngas from the gasifier (or the H2 rich gas normally sent to the turbine). In the case where the gasifier produces syngas for downstream chemicals production in addition to power production, then a balance between power generation and chemicals synthesis could provide the necessary flexibility.

Industry will continue to further drive improvements in all areas above providing a favourable landscape for CCS is in place, with a first wave of projects being developed and a clear vision of an ongoing market developing closely behind the first wave.

## 4.4 Developing the CCS supply chain

Developing the supply chain for components of CCS has the potential to bring down the costs of components. The supply chain for CCS will develop as a favourable landscape for a CCS market is created and suppliers can foresee a smooth pipeline of projects. On the other hand if roll-out of CCS happens too quickly, it could mean that existing supply chains cannot cope with demand that perversely would increase costs for CCS project developers for bottle-neck components.

A developed supply chain will be one where:

- supply of all equipment (e.g. packings, heat exchangers, compressors, etc) and related raw materials (e.g. steel) is possible within reasonable timescales to meet demand;

- a suitable level of competition between equipment suppliers drives efficiency, innovation and ultimately lower costs; and

- standardisation and significant volume of orders allows expansion by manufacturers towards a minimum efficient scale of production.

However, there is a tension between providing incentives for equipment manufacturers to remain engaged in early projects, while bringing in competition in the longer term to lower costs. Standardisation too can be a double-edged sword in that standardisation to the 'wrong' standard could limit the ability of a firm to export technology to wider global developers.

The extent to which supply chain effects will lower costs in the 2020s will depend on how rapidly the CCS supply chain can develop and how large a supply chain is required to significantly bring down component costs.

## 4.5 Next generation capture technologies

Beyond the current suite of capture technologies currently being deployed at pilot-scale around the world is the next generation of capture technologies, loosely classed as technologies at the laboratory- or bench-scale. These technologies have the potential to enable step changes in capture costs but are often based on very different processes to current capture technologies.

Opinions in the Task Force differ about the timescales for development of these newer technologies, but it is generally considered that they must go through at least two levels of scale-up before they would be ready for commercial deployment. For this reason they are really only suitable for inclusion on a wide scale from the late 2020s onwards.

There are many different technologies at this scale of development and it is not possible to say which of these will offer the greatest commercial attraction in the long run.

Four example technologies discussed were:

- Alternative technologies suited for gas/CCGT post-combustion such as flue gas recirculation.
- Advanced oxygen generation technologies (e.g. non-cryogenic, membrane), whichhave the potential to drive a step change reduction in the cost of oxygen and a corresponding reduction in oxyfuel CCS costs.
- Chemical looping, which can be viewed as an advanced oxyfuel process whereby the ASU is eliminated.
- Advanced post-combustion capture such as the Regenerative Calcium Cycle (RCC) process, whichoffers the possibility for a step change reduction in energy consumption – see box below.

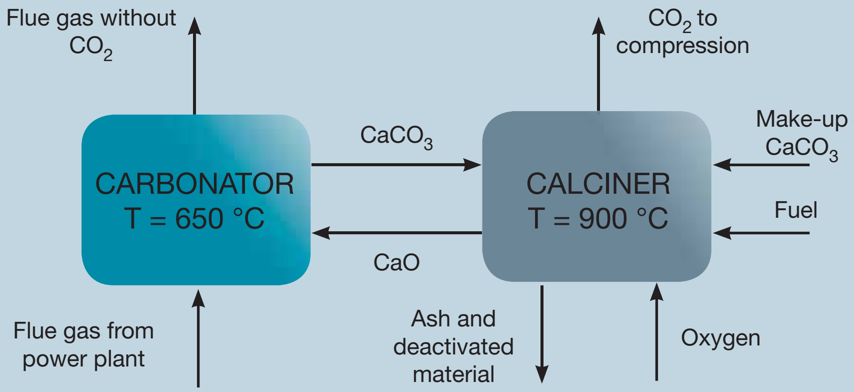
**Agreed Action: R&D funding for future technologies should continue from both industry and Government to create cost reductions beyond the incremental reductions available from existing technology.**

### Example Next Generation Technology: Regenerative Calcium Cycle (RCC

The Regenerative Calcium cycle (RCC) is a post-combustion process that operates at high temperatures (600-750Deg C in the absorber) and (900 Deb C in the regenerator) and utilizes a solid absorbent, lime (CaO). In the RCC process, CaO absorbs the $CO_2$ from the flue gas, in a carbonator. The CaCO3 formed is transferred to a calciner, where the $CO_2$ is released by increasing the temperature to approximately 900C. The stream of highly concentrated $CO_2$ is ready for compression and storage, whereas the regenerated CaO is transferred back to the carbonator closing the Ca-loop. The following chemical reaction describes the capture and release cycle for $CO_2$:

$$CaO\ (s) + CO2\ (g) \ \square\ CaCO3\ (s),\ \Delta H = -178\ kJ/mol$$

Because the reactions take place at elevated temperatures, there is a great potential for optimisation through efficient integration into a power plant or industrial plant (e.g. cement). A further evolution of the technology envisions the use of heat above the level of the power plant steam cycle through the integration of the calciner into the boiler thereby making use of 'indirect calcination'. Such a solution has the potential for a high rate of $CO_2$ capture with minimal energy penalty on the host power plant.

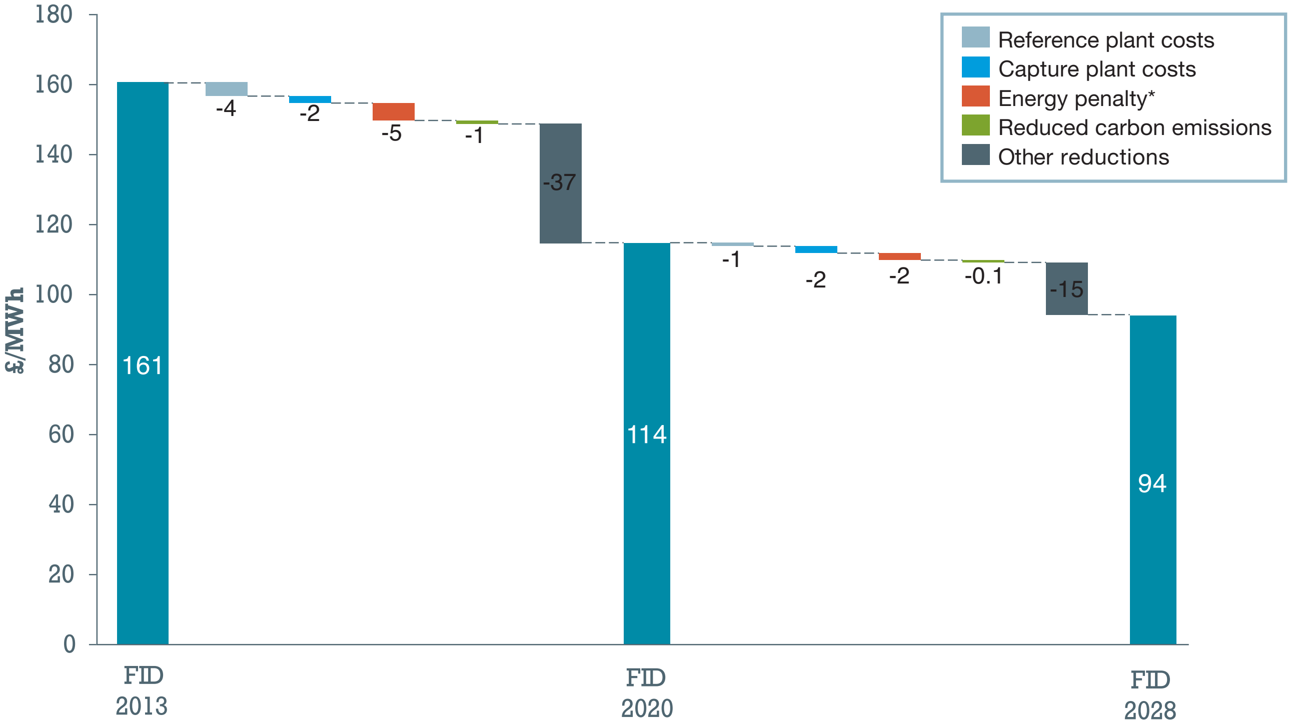



Development of new technologies such as RCC require continued R&D but have the potential to lead to significant longer term improvements in CCS technology beyond 2020.

## 4.6 Conclusions on generation and capture cost reduction opportunities

Figure 2 summarises the cost reductions that can be accessed through improved performance of capture technologies. The 'Other reductions' category includes the cost reduction measures achievable by the other cost reduction pathways in this report. These are discussed in Chapters 3 above and 5 below.

Figure 2 – Potential cost reduction mechanisms relating to improvements in capture technologies (real 2012 £/MWh)




*Includes host plant costs and additional fuel costs

The Task Force estimates that generation and capture costs could drop from £116/MWh (with a range of £104-125/MWh across technologies) for early projects reaching FID in 2013 to £96/MWh (£88-106/MWh) for plants reaching FID in 2020. In the late 2020s generation and capture costs could drop further to £87/MWh (£82-93/MWh). A breakdown of modelling assumptions and costs is provided in Annex A.

In line with Mott MacDonald low cost path assumptions, the model assumes continuing technological progress in the underlying Reference Plant, manifested through capex reductions:

- Post-combustion coal and oxy-combustion coal: £1,500/kW, £1,400/kW and £1,400/kW (in 2013, 2020 and 2028 respectively).
- Post-combustion gas: £550/kW, £500/kW and £500/kW (in 2013, 2020 and 2028 respectively).
- IGCC[8]: £2,200/kW, £2,000/kW and £1,900/kW (in 2013, 2020 and 2028 respectively).

In addition to Mott MacDonald assumptions, the model also assumes that reference power plant efficiencies also improve through time[9]:

- Coal fired power plant: 43%, 45% and 45% (in 2013, 2020 and 2028 respectively).
- Combined cycle gas plant: 54%, 56% and 56% (in 2013, 2020 and 2028 respectively).
- IGCC: 43%, 45% and 45% (in 2013, 2020 and 2028 respectively).

Mott MacDonald low cost path cost-reduction rates have been considered by the Task Force and although there is uncertainty and a range of opinions over such numbers, they are considered as a valid assumption basis.

Whereas cost savings arising from improvements in reference plant technology are largely focused in the nearer term (before 2020), capture plant improvements are seen to have similar cost saving effects both pre- and post-2020. The costs assumptions assume that reduction occurs at different rates for different elements of the capture process, with average reductions in capture plant capex as follows:

- Post-combustion coal/gas: 10% before 2020 and a further 13% by 2028.

- Oxy-combustion coal: 10% before 2020 and a further 14% by 2028.

- IGCC: 2% before 2020 and a further 7% by 2028.

Concomitant with these capex improvements, we also assume a steady reduction in energy penalty (representing overall improvements in the capture process):

- Post-combustion coal and oxy-combustion coal: 25%, 18% and 15% (in 2013, 2020 and 2028 respectively); original Mott MacDonald low cost path efficiencies were 25%, 23% and 18%.

- Post-combustion gas: 19%, 14% and 11% (in 2013, 2020 and 2028 respectively); original Mott MacDonald low cost path efficiencies were 15%, 14% and 11%.

- IGCC: 17%, 16% and 12% (in 2013, 2020 and 2028 respectively).

Additionally, in line with Task Force recommendations, we assume an increase in $CO_2$ capture rates of the plants (increasing from 85% to 90% between 2013 and 2020).

**The reduction in cost of capture technology is particularly difficult to predict because technological development, by definition, is not a known quantity. Also, the response of the supply chain to a substantial, competitive CCS market alongside other demand sectors is difficult to predict. Whilst this generates uncertainty in costs savings, many Task Force members think there is the potential for considerably greater savings than those above based on previous experience with other technologies.**

[8] Estimates of IGCC capital costs vary greatly, and as such are they are regarded by the Task Force as subject to a greater range of uncertainty than the other technologies.
[9] Mott MacDonald assumptions assumed constant efficiencies throughout the modelled period of 40% in coal plants and 53% in gas plants.
[10] The energy penalty figures are dependent on the reference plant efficiency, therefore care must be taken when comparing such numbers from project to project.

# Achieving affordable finance for CCS chain

# 5

This section presents the main findings for cost reductions from the Commercial and Finance workstream.

All elements of the Carbon Capture and Storage chain are by nature capital intensive; therefore the efficiency of the financing structure has a large influence on the overall LCOE.

In general there is significant interest in CCS from certain financial institutions but the overall perception is that risk is high, which in turn constrains financing options and increases costs above those for conventional power projects.

Current large-scale CCS projects worldwide are generally funded via a mix of capital grants, equity, subsidised loans (from multinational development banks, export credit agencies etc) and limited scope commercial loans. However, the nascent nature of the industry means that there are no standard finance structures in place for CCS projects and the terms of future commercial loans are highly uncertain.

## 5.1 De-risking the CCS chain

One of the key mechanisms by which increased learning and experience will lower costs is through lower cost of capital, including financing for all elements of the CCS chain. The mechanism by which these costs reductions are realised is through:

- A reduction in the equity hurdle rate required by firms to invest in CCS as they better understand and price the particular risks of the industry;
- An increase in the equity value attributed to later years of an asset life (through greater perceived certainty in longer-term revenue streams and costs);
- An increase in the gearing available to projects as well as increasing debt liquidity available to CCS overall, leading to an improvement in the available terms of debt (margins, ratios, covenants etc) as the perceived risks of the industry are better defined and understood through experience.

There is considerable overlap with the other workstreams for de-risking the CCS chain. However there are some specific routes by which cost saving can be achieved which were discussed by the Commercial and Finance workstream.

### 5.1.1 Optimal industry structure for risk management

As the CCS landscape develops, the risks in the chain should be more efficiently allocated to those parties that are best able to manage them, thus reducing the overall cost of risk associated with CCS.

The ability of the industry to allocate the different risks will depend on many things, not least the regulatory and policy environment for CCS which will have a material bearing on the industry structures established. Different interventions can lead to a variety of industry structures, in particular in the $CO_2$ transport and $CO_2$ storage sectors of the chain, which could make risks more or less acceptable to different stakeholders.

Below we outline some potential industry model structures that were discussed as part of the workstream workshops. Appropriate industry structures for CCS equipped power stations are likely to change over time as the risk structure of the industry evolves.

**Fully integrated (JV) model**

This is a fully integrated (or Joint Venture (JV)) project structure where each ‘full-chain’ capture, transport and storage project is owned by a Special Purpose Vehicle (SPV). The SPV is set up and managed by JV partners who may be specialists in one particular aspect of the chain with the SPV integrating the full chain.

This will be optimum in terms of risk sharing as many of the interface risks are internalised and profits and costs can be shared However, JV partners operating in different sectors can have very different approaches to business and more importantly risk/return expectations making this approach challenging to set up. From a financing perspective though, this could be an attractive structure if the JV partners were reputable and creditworthy entities and if the JV/shareholder agreement adequately addressed these differences to ensure risks were well managed.

A JV model is likely to be most applicable to single or related projects but could also be applicable to provision of transport and storage infrastructure to serve hubs of multiple capture projects.

**Market led, disaggregated industry model**

In this model, each component of the CCS chain is owned and operated by a different entity with the relationships governed by commercial contracts. These contracts could have a variety of forms including availability based, take-or-pay, ship-or-pay and variable charge payment mechanisms and would be regulated by standard third party access (TPA) requirements.

This model would potentially provide the developers and operators of each chain element with the strongest incentives to manage their own construction and operational

[20] Source: UKERC, ‘Investment in electricity generation: the role of costs, incentives and risks’, 2007

risks. However it also increases the potential for, and impact of, project-on-project type risks where individual elements of the chain may be unduly exposed to operational risk in other components of the chain. Whilst this can be mitigated with the contractual arrangements between the individual links, the negotiation of these contracts and the ability of the individual companies involved to honour their obligations is crucial to making the disaggregated model work.

It is not currently clear what the optimal approach would need to be to fund such a disaggregated model: a 'trickle-down' of revenue from capture to transport to storage combined with the other issues described above may make it difficult to finance some elements of the chain.

**Regulated returns/revenues for transport and storage sector**

Establishing a central or regional transport and storage entity could help to significantly lower the cost of capital and financing if based on a regulated asset base or similar structure; examples are the gas and electricity grid and to a certain extent, the Offshore Transmission Owners (OFTOs) for offshore wind. Such a structure would enable socialisation of the costs of transporting and potentially storing the $CO_2$, leading to lower financing costs than the same transport sector which was funded on a purely commercial basis. However, the structure put in place would also need to encourage the minimisation of costs and ensure that the scale of the network was suitable to meet the expected development of the industry.

Additionally it is widely recognised that the UK government would not accept such an industry on its balance sheet: a private sector 'monopoly' provider would be required, but examples do exist. The appropriateness of this type of model depends largely on the expectations for the wider development of the industry as this type of model will clearly be more appropriate for a more mature industry with hubs and multiple capture plants than single point to point projects that may emerge from the Commercialisation Programme.

**Agreed Action: Consider how the business model for CCS in the UK should migrate away from early end-to-end full chain projects to projects more suited to cluster development.**

### 5.1.2 Contracting structure

As the first CCS projects are developed as part of the CCS Commercialisation Programme, a commercial structure will be established governing parties' responsibilities. There is a clear opportunity for these early commercial agreements to form the template for subsequent projects, as was the case for the early CCGT power projects in the UK and Independent Water and Power Plant (IWPP) projects in the Middle East. The ability for CCS projects to look to these contracting structures as guidelines for new projects will improve the efficiency of executing subsequent projects and the Task Force believes that there are potentially significant financing benefits from defining an early robust 'copy-cat' model for commercial contracting and risk sharing which will contribute to the cost reductions in the industry on both development and financing.

Competing forces influence the desirability, in contracting terms, of separation of the chain into smaller individual components:

- Different elements of the chain (generation, capture, transport, use, storage) may require very different financing and contracting structures to make the business commercially viable. However;
- 'Project-on-project risk' (or the risk arising from interactions between sequential parties in an interdependent group – sometimes known as 'chain-risk') will increase as the number of links in the chain is increased. In other words, contingency is, in part, a function of the contractual interface and the more interfaces, the more the potential for layering of contingencies – other things being equal, reducing the number of contracts reduces this inefficiency in contingency costs.

To the extent possible, establishing a standardised commercial and financing model for CCS will be beneficial if it is appropriate for future CCS projects. However, the model will need to be flexible enough to cope with unique features of individual projects, not least differing capture technologies and pipe-storage configurations.

**Agreed Action: Develop an industry view of a bankable project contract.**

### 5.1.3 Characterisation or 'proving' of storage

For financial institutions, generation is understood and $CO_2$ transport has been widely demonstrated in the US and elsewhere. In particular, $CO_2$ use and storage in the UK are much less familiar to financial institutions even if there is some precedent in other industries that use project finance services.

The Task Force believes that these storage risks are regarded by the finance community as being a major current issue for financing CCS. Without a low risk profile for the storage element of the chain, CCS projects will find it difficult to get low cost (or possibly any) external finance, thereby increasing costs and limiting the scale of any individual CCS power plant (further reducing potential costs savings from power plant scale – see Section 4.4).

Financeable CCS in the early 2020s therefore requires a storage solution that is generally regarded as 'proven' and demonstrably fit for purpose in order for financing to be raised, the focus of which will be:

- characterisation of storage sites and a track record of storage injectability and $CO_2$ dispersion behaviour as expected in key localised areas; and

- diverse storage options to provide contingency, so that (collectively) the probability is 'bankable' which ultimately requires several 'proven' storage options.

Alternatively, storage will have less impact on overall financing if the financial performance of the rest of the chain is somehow insulated from the storage risk. This could be achieved by a separate storage entity assuming the storage risks although it is not clear which entity could perform that function at present.

The need to address storage risks has been highlighted by the Planning and Infrastructure workstream as well as the Commercial and Financial workstream. It is discussed in more detail in Section 3.2.

### 5.1.4 Demonstration of capture technologies

The Task Force believes, in addition to the storage risks outlined in 5.1.3 above, capture technologies at a scale required for application to power stations are still regarded as novel by the finance community and as such are regarded as a high risk element of the CCS chain for power stations. This risk perception for current capture processes currently creates an issue for financing CCS.

The Commercialisation Programme in the UK and capture projects elsewhere in the world have the opportunity to help mitigate these risks by the early 2020s through the successful deployment of operational CCS plants (as discussed in 2.2). Financeable CCS requires a capture process that is technically proven in order for financing to be raised, the focus of which will be:

- construction risk for the capture units; and
- technical performance of the capture process post commissioning (rate, costs etc).

As technologies are tested at scale we would expect the risk perception of those technologies to decrease although the variety of options for each CCS project (such as geography, generation technology, fuel-type, other heat loads etc) will mean that this de-risking process will take time.

As 'next generation' capture technologies are developed over time, they will also need to undergo a similar process of testing both at scale and in a variety of conditions to lower their technical risk and make them financeable.

## 5.2 Ensuring funding mechanisms are fit for purpose

A fit for purpose funding mechanism which matches the cost structure of the project and provides revenue certainty (subject to performance) will lower the perceived risk of the CCS project, lowering the hurdle rates for CCS projects and giving access to low cost finance (as described in the wider de-risking description – see Section 5.1).

**Electricity market reform**

The UK currently presents one of the most attractive potential investment environments in the world for CCS owing to its geography, skills base and suite of potential support mechanisms for CCS. The EMR process has put in place potential long-term remuneration for CCS in line with other low carbon generation options through the CfD mechanism.

After the commercialisation programme the strike price, as provided by the CfD mechanism, is intended as the primary method of support for CCS. However, the technical details of the CfD mechanism are still being decided and, the initial strike prices will be set by negotiation before becoming technology neutral in the 2020s.

The following key CfD features, some of which have already been discussed as part of the EMR process, have been highlighted by the Task Force as having the potential to offer value for consumers by making CCS more financeable without increasing the absolute costs to consumers:

- A mechanism to ensure the value of flexibility and firm-availability is rewarded (see Section 6.1);
- Allow renegotiation of CfD strike price after construction to remove construction risks from the project;
- Index the CfD strike price to fuel prices to remove fuel price risks; and
- Present a viable CfD counterparty so that counterparty risk is minimised.

Whatever funding mechanism is used for the CCS chain it will need to be simple enough for financial institutions to understand, model and be confident that the revenues flowing from it are stable, reliable and deliverable in the long-term. Whilst the outline of the EMR proposals are encouraging in this respect the detail will be crucial for the bankability or otherwise of CCS projects.

**Agreed Action: Continue work to develop the CfD structure, and other relevant EMR instruments, with a view to their widespread use in CCS projects.**

**Separate funding mechanisms for T&S sectors**

The current CfD funding proposals for CCS are focused on the power generation sector with the key metric being the delivery of low $CO_2$ power to the grid at the power station fence. Payment for the transport and storage of the $CO_2$ is expected to be covered by the CfD payment.

Where the entities that are transporting and storing the $CO_2$ are separate from the power generator, the current model is for payment for $CO_2$ transport and storage to be via a negotiated contractual relationship. The nature of these contracts will govern the risk profile of the individual elements of the CCS chain.

The CfD mechanism has good potential and, notwithstanding the above points, is regarded as a relatively good mechanism for addressing the risks and creating financeable generation and capture of $CO_2$. However, transport and storage have very different risk profiles:

- As the transport networks have a very high proportion of capital costs they will favour fixed annual payments – they will be particularly exposed to contracts which are based on a per unit fee for delivery of $CO_2$. The power station on the other hand would prefer all payments to be based on a per-unit delivery of $CO_2$;

- Storage operators may need to take speculative approaches to storage characterisation, investing significant sums of money in uncertain sites before a $CO_2$ flow is ensured. They will therefore require higher levels of compensation to account for the risk.

- Use of CO2 for EOR raises another set of issues as the $CO_2$ user will require reliability of volumes when required but also technical flexibility related to the independent operation of the field utilising $CO_2$ EOR.

## 5.3 Continued involvement from financial and insurance sectors

If, as expected, the perceived risks associated with CCS change positively in the medium term to improve the financeability of the industry, there will be increased competition, all else being equal, for the provision of project finance and other services to the CCS sector. This will clearly help to ensure that financing costs of CCS projects are reduced as the industry matures.

The role of the insurance sector should not be underestimated in improving the financing conditions for CCS as they will be best placed to deal with and mitigate certain risks which will still exist within the CCS chain.

Ongoing work within the CCSA and ClimateWise, the global insurance industry's leadership group to drive action on climate change risk, considers the role that insurance might be able to play in helping to manage the regulatory and commercial risks faced by CCS project developers[11].

**Agreed Action: Keep a variety of financial institutions, analysts and insurance companies engaged in CCS so that they:**

- **understand and gain comfort about the full chain of CCS, its technical characteristics and the financing mechanisms in place;**

- **can correctly analyse risks and risk mitigation options; and**

- **can work with the industry and policy makers to provide the financial structuring expertise required to fund the anticipated growth of the industry in an efficient manner with appropriate returns.**

## 5.4 Conclusions on commercial and financial cost reduction opportunities

From a modelling perspective, cost reduction mechanisms in this area are simulated by:

- Incorporating longer economic asset lives in later projects allowing longer term financing (increasing the assumed economic life from 15 years to 25 years between 2013 and 2020 in all sectors). By doing so we move to a figure more representative of (what in later years is expected to be) a more mature industry. Longer economic lives represent the impact of improved financing terms and the potential for progressive refinancing of debt, and drive down costs by, in effect, allowing projects to recoup capital expenditure over an extended period of time.

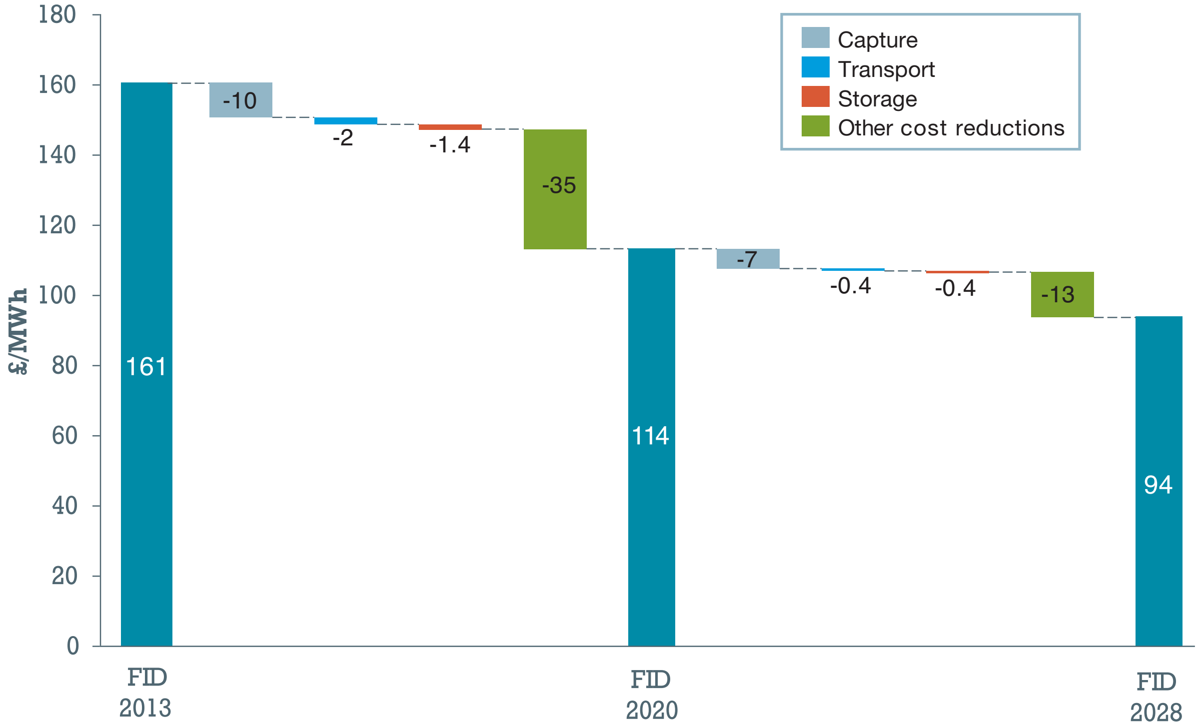
- Reducing the cost of capital:
  - In capture and transport sectors, the cost of capital remains at 10%[12] until 2028 when it is assumed to drop to 8%.
  - In the storage sector the cost of capital is assumed to steadily decline from 15% to 14% to 12% in 2013, 2020 and 2028 respectively.

Figure 3 shows cost reduction mechanisms from accessing affordable finance for the CCs chain. The 'Other reductions' category includes the cost reduction measures achievable by the other cost reduction pathways in this report. These are discussed in Chapters 3 and 4 above.

[11] "ClimateWise (2012): Managing Carbon Capture and Storage Liabilities in Europe" http://www.climatewise.org.uk/

[12] It is noted that the 'correct' cost of capital figure is uncertain even for established industries and differing assumptions can drive very different results for LCOE calculations. The numbers stated have taken the Mott Macdonald report as a starting point and are regarded by the Task Force as broadly appropriate for this kind of analysis. However, it should be recognised that individual Task Force members choose to use (sometime very) different numbers in their own internal analysis.

Figure 3 – Potential cost reduction mechanisms relating to improved financeability (real 2012 £/MWh)




Modelling results indicate that the capture section of the chain has the most to gain from mechanisms that improve financeability; this is to be expected because it retains the largest cost elements.

The cost reduction shown here is actually relatively small for the Transport and Storage sectors. This is because this shows only financial and commercial impacts in isolation. The greatest savings in these sectors are harnessed from the economies of scale discussed in Section 3. In reality the de-risking of the sector as discussed in Section 5.1, will be essential to the financing and building of large scale infrastructure. As such the combined impact of **not** undertaking the cost saving routes discussed in this Chapter would be much greater than Figure 3 indicates due to their necessity for other aspects of cost saving.

# Leveraging the benefits of CCS 6

Developing a CCS industry in the UK has the potential to create significant value not only through low cost power production but also within the oil and gas sector and by stimulating other areas of the economy. Many of these benefits are cross-workstream, and we therefore discuss them separately here.

## 6.1 The value of flexibility

Section 1.1 describes the important role that CCS is envisaged to play in a decarbonised UK electricity mix. There are significant network management benefits to introducing alternative, potentially flexible, sources of low-carbon electricity especially when it is installed alongside intermittent generation.

DECC's Technology Innovation Need Assessment released in August 2012 highlights the potential role of CCS in the UK's power sector:

- Having CCS available (compared to a power sector without CCS) is estimated to save the UK hundreds of billions of pounds in cumulative value between 2010 and 2050. Nevertheless, considerable work remains to demonstrate CCS at large scale and across the entire chain.

- CCS offers many benefits to a low-carbon energy and economic system as it allows the flexibility and energy security benefits of fossil fuel combustion with near-zero GHG emissions.

Therefore not only will CCS provide low carbon generation to the grid, alongside other low carbon options such as renewables and nuclear, it can also provide two additional services:

- Provision of secure power – unlike intermittent forms of generation, CCS can be scheduled so that it has a very high level of availability at times of peak demand on the grid.

- Provision of flexibility – with tightening capacity margins and pronounced deployment of intermittent forms of generation, the maintenance of grid stability is becoming increasingly more challenging for System Operators (SOs). The electricity system must be balanced instantaneously by the SO to maintain the necessary level of electricity supply stability. CCS has the capability to both increase and decrease generation levels relatively quickly (compared to many other forms of low carbon generation) and thus has the potential to play a significant role in ensuring security of supply. That said, flexible CCS is unlikely to compete with OCGTs or pumped storage (i.e. very short-term on-off scenarios), but rather, it would be expected to provide more 'load following' type flexibility which would address day/night transients, and potentially up to an eight hour 'off or idle' period. The CRTF also notes that the requirement for high levels of flexibility is unlikely to be a 'First Generation CCS' issue.

As the proportion of intermittent generation on the grid increases it is likely that the value of these services will increase. It is not currently clear how these benefits will be rewarded for CCS plants under current market arrangements.

**Agreed Action: Develop an understanding of the value that flexible fossil power with CCS can bring to the power sector in the future and explore whether and how CCS generators would be able to capture this value.**

## 6.2 Wider energy system benefits

CCS has the potential to provide value and cost savings beyond the power sector, including through $CO_2$ EOR (see Section 6.3) and also the decarbonisation of:

- industry (see Section 6.3);

- heat; and

- hydrogen production.

Energy system modelling by the Energy Technologies Institute suggests that successful deployment of CCS would be a major prize for the UK economy, cutting the annual costs of meeting carbon targets by up to 1% of GDP (or around £42 billion a year) by 2050.

With respect to the role of CCS in hydrogen production, IGCCs apply a process that produces decarbonised hydrogen in bulk that is then transported and combusted to produce low-$CO_2$ power. There is scope for the hydrogen to be fed into higher value uses and harder-to-access carbon abatement areas and not only in direct large-scale power generation facilities. This includes:

- providing feedstock for industry (as is currently the case on Teesside, Merseyside and elsewhere);

- smaller CHP installations;

- in the longer term, the opportunity to provide low carbon transport; and

[20] Source: UKERC, 'Investment in electricity generation: the role of costs, incentives and risks', 2007

- remote decarbonisation of CCGT power plant through a wider hydrogen network.

The CRTF believes that CCS-produced hydrogen has the potential to be up to 50% cheaper than hydrogen produced by other means. Banking of gasifiers would provide economies of scale benefits and produce sufficient volumes of hydrogen to feed into multiple processes. While appropriate technology for such a system is under development, it would require a high level of integration of the source and use of hydrogen to achieve a viable financial proposition.

**Agreed Action: Investigate how the deployment of CCS can reduce overall energy system costs by cutting across different sectors (power, transport, industry, heat, feeding into pre-combustion hydrogen networks etc.)**

## 6.3 Industrial CCS

Only around 40% of UK GHG emissions originate from the energy supply sector. If CCS is developed for the power sector, there is potential significant further opportunity to leverage the benefits of symbiosis between $CO_2$ capture from power stations with $CO_2$ capture from industrial sources.

In the absence of an existing $CO_2$ transport and storage network the low volumes of $CO_2$ generated at individual sites are unlikely to make underground storage of CO2 a viable option for non-power industrial $CO_2$ sources. The large economies of scale associated with $CO_2$ storage and transport simply make it uneconomic.

However, the industrial processes are such that often CO2 can be captured at a reasonably high purity for relatively low unit cost. If this $CO_2$ can be fed into already existing transport and storage networks then the incremental cost of the additional $CO_2$ saving would be very low.

Although the decarbonisation benefits may be attractive from a UK perspective, industrial CCS is not necessarily economic to industrial emitters. As the $CO_2$ price faced by industrial emitters under the European Union Emission Trading Scheme (EU ETS) is so low – averaging around 8/ tCO2 in 2012 to date – abatement from these sources is not currently economic even though it may be significantly cheaper than power sector decarbonisation.

This situation is expected to change as the EU ETS price increases during Phase III and Phase IV but the timing and extent of this rise is currently unclear. If industrial sectors faced higher costs of emissions earlier (as is the case for the power sector with a Carbon Price Floor) we would expect to see industrial CCS becoming more attractive.

The Task Force believes that encouraging industrial CCS would further reduce UK GHG emissions but also help to safeguard the competitiveness of UK industries as the costs of emitting $CO_2$ under schemes such as the EU ETS increase over time.

**Agreed Action: Investigate options to incentivise the development of industrial CCS projects.**

## 6.4 Encouraging CO2 EOR

CO2 injection into oil fields is one method of recovering otherwise unrecoverable oil from mature oil fields, creating additional income to offset CCS costs, and deferring oil and gasfield decommissioning costs. The Central North Sea (CNS) oil province is mature with many fields set to close in the next decade and therefore suitable for EOR developments. However, developing $CO_2$ led EOR will also require capital investment in new equipment at each field of the order of £1bn.

CCS and $CO_2$-based EOR could fit together extremely well; use of CO2 for EOR provides a way of monetising a waste product, and permanently disposing of the $CO_2$ at the same time. This is a key reason for the financial success of many CCS projects in the USA and Canada.

A word of caution is needed, as not all CNS fields are suitable for $CO_2$ EOR campaigns, and there is no direct experience of offshore $CO_2$ EOR in the CNS or elsewhere. However, several oil companies are actively exploring the option of pursuing $CO_2$-based EOR on a number of fields in the CNS.

Recent work on the overall value of EOR opportunities such as the Scottish Enterprise Study on the 'Economic Impacts of $CO_2$-enhanced oil recovery for Scotland' and the University of Aberdeen's Occasional Paper on the 'Economics of $CO_2$-EOR in the UK Central North Sea' add testimony to this view. However, these studies also identify barriers to widespread deployment of $CO_2$ EOR.

Neither of the above papers takes the step of looking at the potential impact for LCOE of CCS power projects. Only a rough estimate can be made currently of the value that $CO_2$ might attract if it were delivered at pressure to CNS oil field operators. There is uncertainty about both the overall $CO_2$ EOR value and the likely split of value between government, CO2 provider and EOR developer. Indeed, these values are likely to vary significantly according to the features of each field/project. However, based on US experience the value could well cover the cost of conventional $CO_2$ storage, and perhaps some of the transport costs as well. This might decrease electricity costs by £5-12/MWh for gas CCS and £10-26/MWh for coal CCS.

It is the view of informed Task Force members, and others who have been consulted, that $CO_2$ EOR investments will be actively pursued, and probably sanctioned on some fields, as soon as there is confidence that $CO_2$ is being delivered to the CNS; and that this will reduce the cost of electricity from some of the power project investments which are expected to be built in the early 2020s. This can act as a stimulus to:

- maintain or extend existing and future offshore infrastructure;
- provide high-quality employment as well as protecting the existing offshore service industry; and
- provide oil and gas tax revenues.

**Agreed Action: Stakeholders to work together to deliver measures that facilitate $CO_2$ EOR in the UK.**

# Gap analysis

7

## 7.1 Gap analysis objectives

A key goal for the Cost Reduction Task Force is to recommend and initiate a series of actions that have been recognised by the Task Force as fundamental to the achievement of cost reduction opportunities identified within the Interim Report.

In this regard, the Interim Report proposed a series of 'Candidate Actions' which were subsequently allocated to individual CRTF workstreams (as described in Section 1.4) for purposes of gap analysis. At that stage, a number of Candidate Actions were identified as being applicable across workstreams, and for this reason, a fourth workstream was established in order to consider such cross-cutting issues.

The gap analysis methodology employed by workstreams for this deliverable was as follows:

- Agreeing upon the necessity and nature of the proposed 'Candidate Action' to form an 'Agreed Action'.
- Conducting a Gap Analysis on the Agreed Action to identify:
  - What activities are currently being undertaken (generally by members of the Task Force) which meet (partially or wholly) the action goals – it is recognised that significant other work is ongoing by parties outside of the Task Force group, especially in groups outside of the UK.
  - What activities (next steps) must be undertaken in addition to meet the gap between what is under way or planned and what is required to meet action goals.
  - Prioritising gap items to recommend next steps towards realising the cost-reduction potential of CCS.
  - Candidate parties to lead on each item **[recorded in bold square brackets]** including the way in which the next step will be monitored.

These actions aim to determine how the CCS industry can take the required next steps towards achieving the cost reduction opportunities identified by the Task Force. To this end, the identified next steps focus on recommended short-term practical activities and, in many cases, will be the first of many stages required to fully realise the opportunities for low cost competitive CCS in the UK.

The resulting actions and next steps from these meetings were further refined through input from workstream champions and individual Task Force members before being discussed and agreed with the full Task Force. Below we summarise the Gap Analysis for each action.

## 7.2 Planning infrastructure workstream

### [IN1] Ensure optimal UK CCS transport and storage network configuration (Section 3.1)

#### Agreed action

*Ensure that configuration of the transport and storage system for early projects takes into account likely future developments of $CO_2$ storage hubs and associated pipeline networks, to minimise long-run average costs.*

#### Further description

Future projects need to build on opportunities created by early projects to create low cost storage and transport solutions. However, Government and developers should also take account of foreseeable future demand in current design of transport and storage infrastructure (e.g. for projects supported through the CCS Commercialisation Programme) to ensure that the design of early projects maximises those opportunities. Designs should also take account of potential to capture other industrial emissions.

#### Current work in progress

- Regional group studies on CCS opportunities have highlighted hub benefits including Thames, Teeside Yorkshire and Scotland.
- The Commercialisation Programme activities will largely set the initial configuration of the transport system.
- The Crown Estate and British Geological Survey (BGS): the '*CO2STORED*', project facilitates access to the ETI storage database providing high level geotechnical detail on potential storage sites.
- The Crown Estate and BGS: 'Storage Portfolio', using BGS data and the '*CO2STORED*' database as a first phase screening of the UK's best storage sites, taking account of surface and subsurface constraints.
- The Crown Estate: Preparation of a knowledge base and assessment framework for planning pipeline infrastructure including reuse of existing oil and gas pipelines.
- Forthcoming ETI Report: '*Optimising the location of CCS in the UK: Current understanding, gaps and policy issues*' (due to be released in 2013).

[20] Source: UKERC, 'Investment in electricity generation: the role of costs, incentives and risks', 2007

**Gap**

There was broad agreement with the Taskforce that recommendations for the configuration of the transport and storage system are necessary (such as diameters, junctions, minimum specifications offshore and onshore) but that a rigid map may jeopardise the consenting process. There is a lack of coordination between different studies at present and a need to:

- Take account of the current commercialisation programme in future plans – disclosure from the commercialisation projects would be extremely beneficial.
- If possible, feed into ongoing FEED for the CCS Commercialisation Programme to maximise option value of early projects; thus, the influence of this action must be felt early.

**Identified next steps**

- **[The Crown Estate]** to form a steering group (provisionally called the **'UK $CO_2$ Storage Development Group')** which will manage working groups including regional study members, Commercialisation Competition projects, key experts (e.g. ETI and SCCS) and input from DECC EDU. The group should aim to unlock cost reductions; maximise benefits of scale and decrease technical, commercial and financial risk in storage.
- To maximise benefits of early transport and storage configurations, the **[UK $CO_2$ Storage Development Group**] should identify options for the UK $CO_2$ transport and storage systems for both early CCS projects and future CCS projects, in order to minimise long-run average costs. The recommendations should apply for the whole of the UK. These recommendations should be able to feed into national policy statements, FiT funding decisions and FEED studies in the Commercialisation Programme.

The UK $CO_2$ Storage Development Group should report back on this to industry (CCSA) and Government.

**[IN2] Facilitate potential $CO_2$ injection into multiple stores (Section 3.1)**

**Agreed action**

*Consider how to ensure contracts and licences can be structured flexibly enough to allow $CO_2$ to be injected into alternative stores by agreement between storage owners.*

**Further description**

Allowing $CO_2$ currently flowing from projects into existing stores toflow, at some point in time, into new stores can lead to lower CCS costs in the longer-term as:

1. The development of the $CO_2$ storage system will lead to interconnection and hubs and increased flexibility in the physical storage system. This increased flexibility will lower costs by reducing risk and the cost of capital and increasing the use of storage and injection assets.
2. The $CO_2$ can be injected into currently unused stores in close proximity to characterise them for potentially a much lower cost than other characterisation options.

The first of these is a longer-term issue, which is currently understood by storage developers (and built into their 'maturity staircase' business models). The second is less well understood and has the ability to benefit the industry and decrease risks/costs in the short term (although the benefits will not necessarily accrue to those parties developing the first project).

In addition the CRTF is of the opinion that, as it stands, the CfD scheme may hinder projects from injecting into multiple stores.

**Current work in progress**

- Scottish Enterprise and Scottish Carbon Capture & Storage (SCCS): 'Central North Sea – $CO_2$ Storage Hub'. This work sets out a number of possible scenarios for the future of CCS in the Central North Sea and highlights the value of hub development. To add to this, Scottish Enterprise has just commissioned a study led by Element Energy and including Dundas, Amec and SCCS, to look at building on this proposition in more detail.
- Scottish Enterprise, SCCS, BGS, The Crown Estate, Shell: 'CCS Multistore'. This project involves the development of a geotechnical model to accurately depict the effects of multiple storage sites in close proximity to each other. Among other benefits, this will develop a knowledge base which will enable the development of an itemised list of site characteristics and modelling techniques and a process for the leasing of large aquifers.
- UCL: 'Carbon Capture Legal Programme' (CCLP) examines specific and wider legal issues with $CO_2$ storage.

**Gap**

- While there is a body of work on this issue it does not address this Action directly.
- Resolution of two potential identified barriers:
  - Current and future contracts or licences may not be structured flexibly enough to allow $CO_2$ to be injected into alternative stores by agreement between storage owners.

– $CO_2$ used in characterisation of new reservoirs (which then does not resurface) may well not qualify for EU ETS.

**Identified next steps**

- Ensure contracts, licences and leases (for Commercialisation Programme projects and beyond) are structured to allow $CO_2$ to be injected into alternative stores, by agreement between storage owners. **[OCCS, DECC, The Crown Estate]**

**[IN3] Promote characterisation of $CO_2$ storage locations to create maximum benefit from the UK storage resource (Section 3.2)**

**Agreed action**

*Examine the options for characterisation of storage areas for $CO_2$ in the UKCS and recommend a way forward. The objective is to make storage bankable from a commercial and technical perspective, including via the reduction of 'exploration' risk premium.*

**Further description**

Characterisation of potential storage resource is fundamental for reducing risk (and therefore cost) and for producing approved and bankable reserves. This issue is particularly pertinent because the characterisation process itself entails long lead times (particularly in the case of storage aquifers).

To date, characterisation of potential resources has not yet been progressed sufficiently. Relatively speaking, considerably more effort and money has been invested in the 'discovery' of potential resources than in their 'characterisation'. The underlying reason for this is principally that characterisation stages of resource development are considerably more expensive than discovery stages as they require, for example, a concerted drilling programme and 3D seismic analysis.

Coordinating the characterisation process has the potential to attain significant cost reductions. The fundamental question is: how should this coordination be achieved? For example, should it be through central planning and control, or through exposure to private sector and market rules?

**Current work in progress**

- Projects run by The Crown Estate (in collaboration with BGS, Durham University, Herriot-Watt University, the Energy Technologies Institute as well other CCS stakeholders are contributing to the overall picture for storage discovery and dissemination of knowledge on storage potential and opportunities.

- The Scottish Government is developing a joint industry characterisation-phase project that has the potential to provide valuable insight into this issue. Though large for an R&D project, it is likely to be in the range of tens of millions of pounds rather than the hundreds of millions that will ultimately be required for a large-scale characterisation project.

- National Grid and the Energy Technologies Institute (ETI) are conducting the UK's first drilling assessment of a potential saline formation $CO_2$ store at a site 70km off Flamborough Head in Yorkshire. This will involve drilling up to two wells in the seabed to gather data to confirm that carbon dioxide can be safely and permanently stored at the site, while also confirming the scale and economics of the store.

**Gap**

Considerable storage discovery work is under way, but there is little characterisation work going on. . There is also a significant amount of privately held geological knowledge which is relevant to storage characterisation. Fundamental questions remain about to the amount of coordination required for such characterisation work (a wide range of views exists on how to take this forward, and there is no good data to suggest one way or the other). There is currently no workgroup looking into this on a UK scale (although some regional studies have looked at some of the questions).

**Identified next steps**

The **[UK $CO_2$ Storage Development Group]** (proposed in IN1) to examine options for characterisation of both storage areas and also specific sites for $CO_2$ storage in the UKCS, with a view to making storage bankable from both a commercial and technical perspective and to ensuring appropriate geographic spread of characterised stores and hubs (Central and Southern North Sea, and Eastern Irish Sea). Ultimately additional steps needed to bring forward investment in storage capacity in line with demand need to be recommended.

Suggested scope of work includes:

– Identify/propose a series of shared-cost programme options (three or four 'straw man' pre-commercial models, for example, a 'UK Storage Board' model and a 'hub-based' model).

– Work out the pros and cons and locational implications of each option.

[13] Geographically defined CO2 storage opportunity that is characterised and publically available (as a data set and a description of overall features) whether or not licences have been granted for all or part of the area.

## 7.3 Generation and capture workstream

**[GC1] Increase scale of generation and capture plant (Section 4.1)**

**Agreed action**

*Projects developed in the UK following those arising from the Commercialisation Programme should be of a size much closer to the full size unabated plants available, in order to capture the economies of scale that should then be available.*

**Further description**

The first set of commercial projects following the Commercialisation Programme should be in the 600-1000 MW range to enable access to cost savings from economies of scale. There is no technical restriction on scaling-up to this size (key equipment will increase in size as projects develop). However, there is a need to address the risks inherent in transitioning to larger sizes and this process will take time. A clear project pipeline is required to provide incentives for vendors to invest in developing larger designs.

It is also imperative to ensure that decisions on scale (including decisions pertaining to number of units versus size of units) are made on a commercial basis and not hindered by policy. Thus, when projects apply for CfDs, they should not be limited by a size range.

**Current work in progress**

- Current early-stage projects (including those in the UK Competition) are in the range 200-450 MW. Design issues related to these sizes are being addressed in these design studies and will be further addressed in FEED activities.

- Considerable work (from numerous vendors) has been conducted into designs used for competitive bids; the designs all focus on optimisation and pushing scale limits and represent a potentially vast repository of information. Just considering the UK Competition and the EU demo programme, something in the order of 20-30 design studies of varying degrees of detail have been completed. Though the information is not publicly available, it represents a significant knowledge base gained by the CCS Industry on all issues related to design, including scale issues.

- In addition to the design activities referenced above, several studies undertaken by industry and other organisations involved in CCS have considered large scale plants. These include:

– *'Alstom COE'*: a study which considers 800 MW coal plant and 600-800 MW Gas Plant.

– *'ZEP Cost Study'*: which considers 350MW gas plants, 600MW coal plants and a 750MW lignite plants.

– DECC Discussion Paper: 'Potential cost reductions in CCS in the power sector' (May 2012).

**Gap**

The best information on scale-up is in the range of 200-400MW where competitive bidding has taken place. Work is being conducted on larger scales; however, this is not as refined or as thorough, because no competitive bidding has occurred at this size.

**Identified next steps**

**[DECC]** should not introduce arrangements that limit the size of plant for follow-on and future project development. This will enable project developers to make the right economic choice for their project without being constrained by artificial limits.

**[GC2] Optimise plant design requirements and specifications (Section 4.2)**

**Agreed actions**

*Ensure that the optimal balance between scale risk, equipment redundancy, design margins and required availability is achieved; including the requirement that any constraints (e.g. $CO_2$ specifications), design requirements (e.g. capture percentage limits) or performance objectives (e.g. minimisation of cost of electricity generation) are set with the intended and possible unintended consequences of these limits clearly understood and agreed.*

**Further description**

Government, regulators, other relevant authorities and project developers and their supply chain should avoid setting constraints which cause unnecessary increases of 'compliance' costs. Examples from past experience include: $CO_2$ specifications; capture percentage limits; availability requirements, equipment redundancy/sparing, design margins, etc. For example, incentives for high levels of availability should be driven by balancing commercial and technical drivers rather than a policy requirement which could lead to higher costs.

**Current work in progress**

- Designs which have been completed (including suppliers preparing Commercialisation Programme bids and for projects which have not gone forward) have generated significant amounts of information and have addressed many issues relating to design constraints and impacts on costs.

- It is believed that there has already been a 'relaxation' of some constraints between the early project designs (e.g. Longannet, Kingsnorth) and those now being developed (Commercialisation Programme).

**Gap**

Several of the issues related to design optimisation (including trade-off between design constraints, availability and integration) have been addressed by technology providers and project developers as part of completed FEEDs and design studies, however, the decisions (and drivers) are not known publicly. The main gap is thought to be in the area of Knowledge Sharing. While confidentiality concerns need to be considered, the CRTF believes that there is a real opportunity to share certain experiences related to design optimisation which can benefit the CCS industry as a whole.

**Identified next steps**

- **[CCSA]** to implement a Knowledge Transfer Network (provisionally named the **'UK CCS Knowledge Transfer Network')** involving DECC, competition winners, CCS supply chain stakeholders and academic institutions. The aim of the group will be to enhance cost saving (and value enhancing) potential for CCS projects by promoting and facilitating the flow and review of knowledge and information (with appropriate IP protection), for both Industry and Government, following on from early projects in the UK and elsewhere. This will identify key gaps which stakeholders should address in order to ensure that CCS plays its full potential in the broader decarbonisation of the UK energy system. To ensure effective dissemination of knowledge it is recommended that seminars are held and, wherever possible, information is shared in academic and trade journals.

- Amongst other actions the **[UK CCS Knowledge Transfer Network]** should facilitate the sharing of experiences/issues pertaining to product and process design specifications, scale-up, constraints etc (including potentially reviewing the design requirements of the Commercialisation Programme Competition to identify any specifications that have been/should be changed relative to the first UK Competition).

**[GC3] Examine benefits and downsides of generation and capture integration (Section 4.2)**

**Agreed action**

*The benefits and downsides of integration should be examined from the experience of all early projects, worldwide, in order to incorporate this experience into future designs.*

**Further description**

Integration should encompass not only thermodynamic integration, but also physical integration. However, thermodynamic integration is what most people mean when they consider integration and it is the most challenging from an engineering perspective. It can be expected that higher overall energy efficiency of the power plant and hence lower generation costs can be achieved with greater degrees of thermal integration. However, this generally comes at the expense of plant flexibility, which could be a dis-benefit in future markets if greater flexibility is required.

**Current work in progress**

- Designs which have been completed (including for projects which have not gone forward) have addressed many of these issues.

- Integration and optimisation of capture/power plant is generally well known, will be project specific and can easily be quantified by technology providers, EPC contractors, etc.

- Current performance predictions (and evolution of this) based on an assumed 'optimal' degree of integration. With operating experience our knowledge of how to optimize integration for future projects will improve.

**Gap**

- Impact of integration (especially high degrees of integration) on operability (not considering large flexibility requirements) is unknown and will not be until the current projects are up and running.

**Identified next steps**

Commission a report that examines the benefits and downsides of integration from the experience of all early coal and gas projects, world-wide, in order to channel this experience into future designs. Explore the potential to collaborate with GCCSI and/or ZEP. **[UK CCS Knowledge Transfer Network.]**

**[GC4] Continue R&D funding for future technologies (Section 4.5)**

**Agreed action**

*R&D funding for future technologies should continue from both industry and Government to create cost reductions beyond the incremental reductions available from existing technology.*

**Description/definition**

Achievement of cost reductions for generation and capture will depend on innovations beyond the incremental reductions available from existing technology. The R&D to discover and develop these innovations is necessary now given the lead times through the R&D chain.

The Task Force also acknowledges that it is important to emphasise that the R&D referred to in this Action is not intended to replace existing and forthcoming R&D activities in the area of transport and storage.

**Current work in progress**

The government and its agencies (including DECC, the Research Councils, the Technology Strategy Board , and ETI) are supporting research and development in carbon capture over the full range of technology readiness levels from basic 'blue skies' research to pilot-scale trials. The technologies supported encompass:

- The existing leading technologies (i.e. current 1st generation technologies).
- Next (or 2nd) generation technologies (potentially applicable post 2020), i.e. systems generally based on current generation concepts and equipment with modifications to reduce the energy penalty and CCS costs (e.g. better capture solvents, higher efficiency boilers, better integration, etc.)
- Novel technology and process options generally referred to as 'future (or '3rd) generation' technologies that are currently far from commercialisation (i.e. work that is currently only at lab scale and only likely to be applicable at scale post 2030).

This terminology has been adopted by the various public funding bodies engaged in CCS R&D and in the DECC CCS Roadmap.

Industry and academia have responded to the signals from government with good responses to calls for proposals and provision of matching funding. Recent government funding includes:

- c£55m for Fundamental Research and Understanding;
- c£27m for Component Development and Applied Research; and
- c£43m for Pilot Scale Projects (c1-10MWe).

**Gap**

- The main gap is the funding and activities for the nearer-term R&D work, including R&D linked to DECC's Commercialisation Programme projects.
- There is a requirement for industry and government to reach a consensus agreement of current R&D funding needs.

**Identified next steps**

- R&D funding for capture technologies (1st,2nd and 3rd generation) should continue from both industry and Government to create cost reductions beyond the incremental reductions available from existing technology.
- **[The Advanced Power Generation Technology Forum and DECC]**, in consultation with industry (CCSA) and academia (the UK Carbon Capture and Storage Research Centre), should prepare a realistic analysis of the current R&D situation and its future requirements, in particular:
  - what is being funded and what is not being funded (government perspective);
  - what industry is working on; and
  - recommendations for near term R&D targets.

## 7.4 Commercial and financial workstream

### [CF1] Develop business models for CCS cluster development (Section 5.1)

**Agreed action**

*Consider how the business model for CCS in the UK should migrate away from early end-to-end full chain projects to projects more suited to cluster development.*

**Further description**

There is recognition that, by necessity, the early CCS projects are designed to demonstrate the CCS concepts within the prevailing commercial and policy constraints, rather than to be optimal in terms of size, configuration, commercial structure, risk allocation etc. However, on the basis of the experience gained from the first projects, it can be anticipated that the CCS business model will evolve over time to enable greater optimisation and cost savings for projects through:

- development of, and connection to, clusters incorporating commercial scale projects;
- more efficient risk allocation across the chain; and
- projects focused on specific chain elements to feed into or service other parts of the chain.

Various studies have indicated that cluster development could facilitate additional commercial scale capture projects in the power sector while also encouraging smaller scale industrial projects to develop (although the size and speed of potential benefits is uncertain).

**Current work in progress**

- $CO_2$Sense: 'The national, regional and local economic benefits of the Yorkshire and Humber carbon capture and storage cluster'. This report highlights the economic benefits of investing in the Cluster.
- Scottish Enterprise: *'Peterhead $CO_2$ Importation Feasibility Study'* and *'Central North Sea – $CO_2$ Storage Hub'.*
- Current projects in the CCS Commercialisation Competition are expected to have early stage models of how their projects plan to transition to clusters.

**Gap**

- Following the selection of preferred projects in the CCS Commercialisation Competition there is a need to understand how additional capture and storage will feed into those initial projects and how clusters will develop from these. Having this information early is beneficial for the next phase of projects that will be currently undertaking feasibility studies.
- Business models will necessarily develop but there is a need for efficient knowledge transfer during this evolution process.
- There is a need to identify the most appropriate and effective model(s) for the long term, including any policy to support or facilitate new clusters.

**Identified next steps**

- **[UK CCS Knowledge Transfer Network, DECC]** to facilitate knowledge transfer of current (and proposed) business models for the addition of multiple stores and capture units onto existing networks and hubs. Developing an understanding of these business models will enable follow-on projects to fully benefit from existing and planned infrastructure. If possible the knowledge base should include input from Competition projects and BIS.
- **[Scottish Enterprise]** to feedback to the UK $CO_2$ Storage Development Group and Knowledge Transfer Network with regard to next steps for future business models for CCS.
- The **[UK $CO_2$ Storage Development Group]** (proposed in IN1) to examine options for public and private sector roles in co-ordinating/facilitating the efficient development of CCS clusters, building on the work to develop bankable storage (proposed in IN3).

### [CF2] Ensure funding mechanisms are fit for purpose (Section 5.2)

**Agreed action**

*Continue work to develop the CfD structure, and other relevant EMR instruments, with a view to their widespread use in CCS projects.*

**Further description**

In order for the CCS industry to develop, it is essential that proposed clean power definitions and the proposed contract for difference (and other proposed EMR measures) provide an adequate framework for the implementation of large scale commercial coal and gas CCS projects for all stakeholders, particularly, equity investors and debt providers. It is expected that the first projects will benefit from a 'bespoke' CfD contract negotiated with the Authority on a largely bilateral basis due to the timing of implementation and the first of a kind risks associated with early projects. Follow-on projects, however, will be developed under the more generic CfD arrangements to be implemented as part of the market review.

Whilst the bespoke contracts will provide an indication of the requirements of CCS in respect of the generic coal and gas Contract for Difference, there are significant cost benefits (in terms of risk allocation and financing) in ensuring that the final CfD agreement and other EMR instruments arefit for purpose when implemented to ensure these support rather than hinder development of future CCS projects.

**Current work in progress**

- Draft coal and gas CfD strike prices and a clean electricity definition are to be published in the draft delivery plan in July 2013 (information regarding structure and precedents only, strike prices not expected for other technologies).
- Likewise, the commercialisation process will help determine key elements of CfDs and risk allocation.
- The CCSA is currently compiling a report to feed into this area.
- The ETI and Ecofin Foundation: '*Mobilising private sector finance for CCS in the UK*' (November 2012) highlighted some of the financial community perspectives on EMR and CfD support arrangements.

**Gap**

- In addition to the continuation of current work there is a need for sufficient information to flow out of the Commercialisation Programme on CfD structure to enable the continued development of follow up CCS projects.

- The immediate follow-on projects will require contracts which adequately match their risk profile and the experience in negotiation of these contracts needs to be pooled .

**Identified next steps**

- CCSA to encourage successful projects and Government to be transparent in the structuring, composition and design of CfD to allow future projects and financiers to fully understand the nature of their investments. This step can also potentially be fed back into and be facilitated by the Knowledge Transfer Network **[CCSA, UK CCS Knowledge Transfer Network, UK CCS Commercial Development Group (see Action CF3) ]**

- Recognise that early follow-on projects may have unique first of a kind risks which may require a contract structure closer to the DECC Commercialisation Programme framework rather than the final long term structure. Ensure this is fully taken into account for the next projects **[DECC]**.

- Continue work to develop the CfD structure, the clean electricity definition, and other relevant EMR instruments, ensuring their widespread suitability for use in CCS projects. Government should ensure that electricity market arrangements are suitable for bringing forward investment in CCS. Industry needs to provide clarity on the characteristics the market has to exhibit. **[DECC, CCSA, UK CCS Commercial Development Group (see Action CF3) and the UK Storage Development Group]**

### [CF3] Continued involvement from financial and insurance sectors (Section 5.3)

**Agreed action**

*Keep a variety of financial institutions, analysts and insurance companies engaged in CCS such that they:*

- *understand and gain comfort with the full chain of CCS, its technical characteristics and the financing mechanisms in place;*

- *can correctly analyse risks and risk mitigation options; and*

- *can work with the industry and policy makers to provide the financial structuring expertise required to fund the anticipated growth of the industry in an efficient manner with appropriate returns.*

**Further description**

The participation of the financial and insurance community in the CCS industry will be essential if the industry is to develop on the scale and at the pace required to be effective at delivering low cost CCS. Insurance is a key element of risk allocation across the whole chain and debt financing of projects will be equally critical as project developers and investors are unlikely to be able to finance the scale of investment required on the balance sheet.

Constructive engagement of all stakeholders (including finance and insurance sectors, project developers, The Crown Estate and policy makers) is essential to successfully develop the industry on a commercial scale. Specifically, stakeholders will be required to contribute to the commercial, contractual and technical development of the projects and to be aligned with each other at the point when an investment decision is required.

**Current work in progress**

- The Energy Technologies Institute (ETI) and the Ecofin Foundation (EF) are working on a joint initiative which involves a detailed analysis of what is needed to mobilise private sector capital for CCS. The aim of this work is to help put in place the investment conditions required to attract private sector capital.

- DECC industry days.

- CCSA sponsored briefings/meetings.

- Involvement in backing bids in the Commercialisation Program.

- ClimateWise: '*Managing Liabilities of European Carbon Capture and Storage*' (2012) and ongoing work.

**Gap**

- Continued information flow required between DECC, industry and the finance community. Confidentiality remains an issue, which hinders knowledge dissemination.

- To keep information channels open there is a role for a group to oversee this engagement and be involved in the engagement process.

#### Identified next steps

**[ETI and the Ecofin Foundation]** to build a group of active participants to encourage and enable the continued information flow between DECC, industry and the finance community – provisionally called the **'UK CCS Commercial Development Group'**. ETI and EF, working with SocGen, The Crown Estate and the CCSA, will oversee this engagement and the engagement process. The purpose of this initiative is to create and maintain a group of Bank and Insurance company representatives who actively promote the opportunities for future funding and insurance of CCS projects and help deliver bankable projects. This group should interact with the UK $CO_2$ Storage Development Group to enhance its understanding of performance risks, and the group should also feed information into the Knowledge Transfer Network.

### [CF4] Create bankable contracts (Section 5.1)

#### Agreed action

*Develop an industry view of a bankable project contract.*

#### Further description

One of the key outcomes of the Commercialisation Program has to be an investable and bankable contract framework for use as a template for the industry going forward; otherwise new projects will be costly and slow to develop. However, it should be recognised that it is unlikely that the structure of the first projects will be perfect or fully fit for purpose as compromises will have to be made by the various stakeholders, including government, to kick start the early projects.

We are starting to see the development of these contractual structures and the finance community and advisors are working on making these commercial contracts bankable in order to support the projects during the bid process and into execution. There is significant value in taking this continuing experience, extracting the lessons from this and developing a view on what the optimal contractual framework for the next generation of CCS projects could look like as a guide for new developments and planning.

The action should focus on commercial contracts along the chain, as a separate action has been raised on the CfD FiT. The core contract for examination is likely to be the contract between the capture and the store and the ability to invest in one as independently as possible from the other.

#### Current work in progress

- Within the CCS Commercialisation Competition, extensive work is likely to already have been conducted into developing business models. The successful structures for risk allocation developed as part of this will need to be taken into account when developing future projects.

- CCSA are working with the DECC EMR team for the contracts around CfDs – there may be additional lessons to learn for this action.

- The ETI and Ecofin Foundation are working with the finance community, Government and industry on developing 'straw man' solutions for the key barriers to CCS finance. This includes working with the CCSA to engage with the finance community on contracts around CfDs.

#### Gap

- How will risks be allocated between government and the next set of projects?

- Information from the Commercialisation Competition would be a good starting point, however, there are confidentiality issues. How much information can/will DECC make available?

#### Identified next steps

The **[UK CCS Commercial Development Group]** to focus on how to construct contracts (including the detailed terms of CfDs), that will be needed to make follow-on and future projects bankable. This will include taking evidence from the published Commercialisation Programme ITPD, the experience of the Commercialisation Programme bidders and input from other stakeholders including the finance and insurance sectors.

The resulting publication will include recommendations of contracts that could allocate risks under pre-agreed rules and allow for amendments when circumstances change. This will cover contracts between:

- the members of the project consortium; and

- the project consortium and the UK government.

## 7.5 Cross-cutting workstream

### [CC1] Create policy and financing regimes for CCS from industrial $CO_2$ (Section 6.3)

#### Agreed action

*Investigate options to incentivise the development of industrial CCS projects.*

#### Further description

Industrial greenhouse gas emitters currently face a very low (or even non-existent) cost of emitting $CO_2$, therefore, industry is not incentivised to reduce $CO_2$ emissions in the same way as the power sector (by CCS or otherwise). However the threat of increasing emissions costs represents a significant risk to investments on existing plant and is a potential deterrent to investment in new plant. It is the view of the CRTF that industrial CCS will be instrumental to the future competitiveness of UK industry in a carbon constrained world and that measures should be taken to incentivise this.

Existing opportunities for CCS of industrial $CO_2$ represent some of the lowest hanging fruit for $CO_2$ emissions abatement in the UK, and should be exploited to help achieve UK emissions reduction targets at minimum cost. Additional $CO_2$ flowing into transport and storage networks also has the opportunity to increase use of assets and lower costs to other users.

**Current work in progress**

- In 2012 the UK CCS Research Centre in collaboration with BIS (Department for Business, Innovation and Skills) and DECC organised a series of meetings examining the current status of CCS technologies that would be applicable to UK industries, and further technology developments that might be required before commercial deployment.
- Carbon Capture, Use and Storage (CCUS) report: '*Global Actions to Advance Carbon Capture and Storage in Industrial Applications*'. The report explores why industrial CCS applications are of critical importance, the costs of such applications, identifies measures already underway to progress CCS in industrial applications and recommends further actions.
- $CO_2$Sense: Various reports and studies on CCS in the Yorkshire and Humber region have maintained a strong focus on industrial CCS.

**Gap**

- The work of the UK CCS Research Centre (first bullet above) proposes a number of questions:
  - is more R&D required?
  - how can costs be made more certain?
  - at what point does industrial CCS become affordable? (Carbon price but also competitiveness?)
  - What other market failures are there?
  - Can more cooperation be encouraged?
- The CCUS report emphasises the following gaps:
  - Demonstration of CCS in industrial applications is not being implemented fast enough.
  - CCS is already proven in some industrial sectors (such as natural gas processing) but has not reached the demonstration stage in many crucial sectors such as iron and steel, cement and refining.
  - What is the impact of CCS on competitiveness?
- It is currently unclear what the ideal option is for incentivising industrial CCS (for example, CO2 tax versus power sector offset options).

**Identified next steps**

Work with IEA, BIS and others to create proposed policy and financing regimes for the CCS of Industrial CO2, potentially as part of the approach to development of CCS clusters that deliver value in terms of impact on national emissions reductions and building on the recently published Heat Strategy and other initiatives. **[BIS, CCSA and DECC]**

### [CC2] Continue to develop a UK CCS policy and regulatory framework (Section 3.3)

**Agreed action**

*Assess what future development of the policy and regulatory framework is required to deliver CCS projects.*

**Further description**

The current regulatory framework is sufficient for current projects, however, this framework does not necessarily ensure that future projects can be developed at scale. Particular concerns have been raised around issues of third party access to storage and the inherent uncertainties within such arrangements, including:

- potential impacts that neighbouring stores will have on their respective capacities; and
- leakage issues and implications.

The CRTF believes that a balance of regulation should be achieved which provides a level of certainty to CCS developments and encourages new projects to develop without being overly-prescriptive and thus harmful and costly to innovation.

**Current work in progress**

- CCSA and DECC have conducted a CCS Regulatory and Consents mapping exercise wherein they have compiled a list of all current regulatory requirements for all aspects of a CCS chain (this includes pre-construction, operating and decommissioning phases).
- DECC and the OCCS are conducting significant amounts of commercially sensitive work looking into the future regulatory requirements of the CCS industry. This work addresses both the regulation for projects in the Commercialisation Programme and also consideration

of how the market will evolve in the longer term. A clear steer on the direction of this work and expectations would be very beneficial to the development of follow-on projects.

- The Crown Estate has a comprehensive financial modelling tool which has been used to investigate the impact of policy interventions and government support mechanisms on transport and storage business cases.

- ETI and Element Energy have conducted a study exploring business and regulatory models for CO2 transport and storage, focusing on the market failures and difficulties associated with investment in transport and storage, in particular, examining different permutations of public and private sector roles.

- The ETI and the Ecofin Foundation are building a group of active participants to encourage and enable the continued information flow between DECC, industry and the finance community.

**Gap**

- Further to the above, currently there is no clear guidance on how projects that will follow on from the Commercialisation Competition should expect to be regulated.

- The Marine Management Organisation (MMO) and DEFRA need to consider CCS when designating Marine Conservation Zones (MCZs).

- There is currently no agreed model to deal with contingent storage liabilities, these may need to be brought in line with the commercial storage opportunity.

**Identified next steps**

- Continued engagement between Government, industry and finance to ensure that future development of the policy and regulatory regime is suitable to deliver CCS projects, informed by an understanding of the role that CCS can play in the broader decarbonisation of the UK energy system. In this regard, consider co-ordinating a study drawing on a broad range of perspectives, scenarios about the future role of CCS and relevant experiences from other sectors. Review and highlight the availability of guidance and assurance for follow-on projects and feed into continuing EMR development and delivery plans. **[CCSA, DECC, UK CCS Knowledge Transfer Network, UK CCS Commercial Development Group and the UK Storage Development Group]**.

- Continue engagement and two-way information flow with DECC, MMO and DEFRA on the marine requirements of CCS developers both within the Commercialisation Programme but particularly for next phase projects. Ensure that MCZs are managed so that $CO_2$ transport and storage can be effectively deployed. **[CCSA, The Crown Estate]**.

- Industry experts from [The UK CO2 Storage Development Group] and [UK CCS Commercial Development Group] to work together to understand the genuine extent of storage liabilities and to seek reform to existing arrangements if justified.

### [CC3] Create a vision for development of CCS projects in the UK from follow-on projects through to widespread adoption (Section 2.1)

**Agreed action**

*Development of CCS would benefit from a future vision/ plan that has an assumption that coal and gas CCS will be needed in the UK, rather than that CCS might be needed in the UK.*

**Further description**

One of the key landscape requirements for decreasing costs is confidence from CCS developers that they can expect a steady roll-out of CCS. However there is still some ambiguity in terms of long-term pathways for decarbonising the UK economy, and for roll out of CCS in particular. This creates uncertainty, particularly for those projects that are not supported under the commercialisation process and are currently deciding how to proceed. CCS development could therefore benefit from an overall framework (including EMR delivery plans) that indicates how much CCS is planned, and by when.

The obvious parallels to this are the indications from government on Nuclear site licencing (and associated capacity) bringing in large international firms as well as long-standing EU level renewable energy targets and National Renewable Energy Action Plans (NREAPS).

**Current work in progress**

Regional and devolved administration studies (Yorkshire, Scotland, Thames) have examined how CCS can contribute to widespread decarbonisation of energy.

**Gap**

There is a role for stakeholders to point out in a coherent way those aspects of a plan that are required for further CCS development but particularly targeted at follow-on projects (i.e. immediately post-commercialisation programme).

### Identified next steps

**[CCSA]** to create an industry-led quantitative scenario analysis (potentially including industrial CCS scenarios) for subsequent phases of CCS deployment in the UK, leading to an industry-led but government-supported vision of where CCS is going in the UK (including potentially feeding into EMR delivery plans). The aim is to encourage developers to participate in the next phase of UK CCS projects which will get a CfD but no government grant, and to give guidance to them on taking their CCS projects forward. Government support must be sufficient to give project developers confidence in the future CCS market in the UK

## [CC4] Develop Spatial planning and consenting regimes for the CCS industry (Section 2.1)

### Agreed action

*Development of CCS could benefit from a planning and consenting framework that has an assumption that CCS will be needed, rather than that CCS might be needed.*

### Further description

To maximise the opportunity for continuous roll-out of CCS, the recognition of the need for CCS, and the continuing need for CCS must be present in the planning framework in all its guises, including national and local planning, and seabed usage planning. The planning and policy statements that influence those planning decisions, should have as their basis the presumption that CCS and associated infrastructure will be needed, rather than the view today that it may or may not be needed.

### Current work in progress

- The key input into this Action will be the current CCS commercialisation competition – projects will be proceeding through the planning and consenting process with barriers overcome as they arise.
- CCSA and DECC have conducted a CCS Regulatory and Consents mapping exercise wherein they have compiled a list of all current regulatory requirements for all aspects of a CCS chain (this includes pre-construction, operating and decommissioning phases).
- DECC and OCCS undertaking significant amounts of work in this area.
- Work by The Crown Estate to grant leases for storage and manage access for CCS to both seabed and subsurface formations.
- Ongoing work on local and wider environmental costs and benefits of power and storage, including modelling work by Imperial College London.

### Gap

- Projects beyond the commercialisation process could face delays and uncertainty as they will not have sufficient clarity on the process.
- There is no single source for information/guidance on CCS planning and consenting. If projects are provided with a good base of information to begin with, they will be able to avoid potentially significant risks, delays and costs associated with planning and consenting.

### Identified next steps

- Streamlining of the CCS planning and consenting process, including the provisioning of a guide to be produced as part of the Commercialisation Programme. Earlier implementation of this will allow more projects to benefit (however, an early stage map can only represent current understanding). **[DECC.]**
- Transfer 'lessons learned' from wind, wave and tidal consenting procedures. Where possible this should give rise to recommendations for improving the National Policy Statement for Fossil Fuel Power Generation (which encompasses CCS policy). **[DECC, The Crown Estate.]**
- Review and improve the National Policy Statement for Fossil Fuel Power Generation. Develop a National Strategy for CCS, building on insights and evidence developed by the industry in actions [IN1, IN3 and CC5] **[DECC, CCSA, The Crown Estate.]**

## [CC5] Optimal strategy for locating fossil power stations for CCS (Section 2.1)

### Agreed action

*Undertake activities to develop an optimal strategy for locating fossil power plants for $CO_2$ capture, to optimise the transport of fuel, electricity, water and $CO_2$ across the UK.*

### Further description

Given the inherent expenses associated with transporting $CO_2$ in pipelines, realising the optimal locational arrangement of all elements of the CCS chain has the potential to offer large cost saving opportunities. In this regard, any restrictions imposed (for example, geographical and land use restrictions and those resulting from the potentially large amounts of water required for CCS) should also be considered.

### Current work in progress

- Forthcoming ETI Report: '*Optimising the location of CCS in the UK: current understanding, gaps and policy issues*' (due to be released in 2013).

- ETI is currently developing a capability to model the economics of offshore transport and storage networks and infrastructure, building on their UK storage appraisal.

- Work by Pöyry and Element Energy for the North Sea Basin taskforce comprising a series of reports that examined some (but not all) of these locational issues.

- Regional studies (CO2Sense, Thames Cluster) have already looked at how to develop transport networks considering locational constraints.

- Environment Agency: '*The case for change – current and future water availability*' and '*Environmental Risk Assessment for Carbon Capture and Storage 2011*'. The reports comment on water demand for the power sector (including CCS). In addition, the Environment Agency is also currently conducting a study on future water demand in the power sector.

**Gap**

Considerable high level work has been conducted by various groups, however, no recent study has examined the particular requirements of this Action. Studies are needed to examine how the differing costs of transmission of electricity, fuel and $CO_2$ (and potentially local water resources) can optimally be balanced in the UK.

**Identified next steps**

Following on from work already underway, **[ETI and The Crown Estate]** are to convene industry experts through the **[UK $CO_2$ Storage Development Group]** and the **[UK CCS Commercial Development Group]** to agree recommendations on how to develop and implement an optimal strategy for locating future CCS plant (generation, capture, transport and storage). The recommendations will be based on a fuller understanding of the requirements for optimising fuel, electricity, $CO_2$ and water transport across the UK, in order to minimise the long-run cost of low carbon power generation. This should address whether:

- policies should promote or prefer particular locations for $CO_2$ capture (or whether a more balanced option should be developed);

- 'CCS Readiness' criteria should be changed to encourage a cost minimising future path; and whether

- the National Policy Statement for Fossil Fuel Power Generation (which encompasses CCS policy) could be beneficially revised (potentially feed into next steps in CC4 that also pertain to the development of the National Policy Statement).

Recommendations will be aimed at future projects (rather than those whose location is already decided). This study should also feed into the work on national plans and potentially future CCR requirements etc. Likewise, this work should complement existing studies that have addressed the issue on a local and perhaps more detailed level, and should be published in 2013.

### [CC6] Assess wider energy system benefits (Section 6.2)

**Agreed action**

*Investigate how the deployment of CCS can reduce overall energy system costs by cutting across different sectors (power, transport, industry, heat, feeding into pre-combustion hydrogen networks etc.)*

**Further description**

To plan effectively and maximise the benefits from CCS (both by promoting low cost CCS and creating opportunities for CCS to aid decarbonisation of other sectors) it is important to promote an agreed vision of the full potential for CCS to contribute to a low carbon UK energy system, including future applications beyond the power sector, such as for:

- addressing industrial emissions;

- gasification applications;

- use in combination with bioenergy to deliver negative emissions;

- harnessing the full potential of H2 and syngas from pre-combustion CCS technologies; and

- harnessing the full potential of heat

**Current work in progress**

ETI (ESME modelling of whole system benefits from CCS) have produced a range of scenarios that examine how much CCS would be optimal to deliver a future decarbonised energy system in a variety of scenarios and uncertainties.

**Gap**

- Early studies, such as the above, have made some progress in identifying and quantifying the value of CCS beyond the power sector. However, such studies also recognise that the issue is complex and that it could develop in many ways. Thus, more work is required, not just in elaborating and assessing the value of CCS to the wider energy system, but also to determine how projects can best deliver and capture this value.

- The benefits of physical separation (for example, between a hydrogen production plant and its use in power generation) offer the opportunity for wider decarbonisation opportunities (e.g. decarbonisation of multiple small CHPs) and cost savings, however, these benefits are currently not well defined.

#### Identified next steps

**[ETI]** to publish a report from analysis currently underway, which is investigating the impact of CCS on overall energy system costs (including power, transport, industry and heat) under a series of alternative deployment and intermittency scenarios. If warranted by the analysis, consider where further work might be conducted on hydrogen networks including consideration of the benefits and downsides of physical separation of hydrogen production and hydrogen use.

### [CC7] The value of CCS flexibility to the power sector (Section 6.1)

#### Agreed action

*Develop an understanding of the value that flexible fossil power with CCS can bring to the power sector in the future and explore of whether and how CCS generators would be able to capture this value.*

#### Further description

CCS plant can be flexible to meet the needs of the energy grid if it can be delivered, if it has a value and if policies are put in place to incentivise that flexibility.

Various studies suggest that coal and gas CCS plants have the potential to deliver a high degree of flexibility thereby delivering additional value to the system. However, ultimately, the requirement for CCS flexibility (and the value of it) is a system issue and should not just be considered as a single plant problem. A better understanding of future system requirements is required, this will ultimately facilitate a better understanding of how to incentivise and remunerate the development of flexible capacity in a timely fashion.

#### Current work in progress

- ETI: '*Hydrogen storage and Flexible Turbine Systems*'. A study (conducted with Foster Wheeler) into the economics, technical requirements and potential of flexible pre-combustion systems.

- ETI: '*Operational Modelling Tool-Kit for CCS Systems*' (also known as: System Modelling Toolkit).

- Existing studies (particularly in-house studies by OEMs) suggest that Fossil Fuel Plants with CCS can be as flexible as Fossil Fuel plants without CCS (given today's requirements for flexibility of plants) particularly if certain performance criteria (like capture efficiency) can be temporarily relaxed.

- Pöyry intermittency studies: examine the need for greater flexibility across the electricity market as a whole due to the large scale introduction of intermittent generation capacity.

#### Gap

- Current work on flexibility (mainly centred on current demo projects) focuses mostly on single plant solutions and not on longer term system requirements.

- Considering the future (next 10-20 years) requirements of flexibility, work is required to understand the needs (i.e. how to deliver it) and the value for the energy system.

- Real world evidence of the performance of integrated CCS projects under 'normal' load-following scenarios.

#### Identified next steps

- Conduct a study on what are the performance impacts, limits of and costs to making a power plant equipped with CCS as flexible as current non-CCS power plants. Study to be supported by dynamic simulations and pilot plant and commercialisation project validations. **[DECC and Industry coordinated by the Knowledge Transfer Network]**

- Based on the findings of the above study, it is proposed that **[DECC]** commission a study (most likely requiring consultancy work and potentially using IEAGHG as a vehicle) to examine the economic and commercial value of CCS flexibility to the power sector as a whole. Questions to be answered by the study include:

  - The extent to which CCS can reduce power sector costs under alternative scenarios for 'intermittent' generation and under different degrees of operational flexibility for CCS?

  - What income can you get if you operate flexibly?

  - What structures are in place or are required to remunerate flexible capacity?

  - How much more valuable is CCS (than nuclear, wind, inflexible CCS etc.) because of its ability to provide flexibility (economic value from being flexible in a future electricity system)?

  - Do current market and policy structures incentivise CCS projects to be sufficiently flexible for the future needs of the electricity system? (Including delivery of flexibility once a baseload CfD structure expires and the plant is exposed to market conditions).

  - How do you signal the need for flexibility sufficiently early to drive the correct economic decisions by project developers during the design stage?

### [CC8] Incentivise CO2 EOR to limit emissions and maximise UK hydrocarbon production (Section 6.4)

**Agreed action**

*Stakeholders to work together to deliver measures that facilitate $CO_2$ EOR in the UK.*

**Further description**

$CO_2$-based EOR (and to an extent EHR in general) has the potential to create significant additional value for CCS and the UK as a whole, however, not all fields are suitable for $CO_2$ EOR campaigns, thus the value of $CO_2$ EOR is currently uncertain. Uncertainty also exists in likely splits of $CO_2$ EOR value between government, the $CO_2$ provider and EOR developer and the ratios are likely to vary between projects.

**Current work in progress**

- Element Energy for Scottish Enterprise: '*Economic impacts of $CO_2$-enhanced oil recovery for Scotland*' (2012).
- University of Aberdeen: '*The economics of $CO_2$-EOR cluster developments in the UK Central North Sea/Outer Moray Firth*' (2012).
- SCCS et al.: '*Opportunities for $CO_2$ Storage Around Scotland*' (2009).
- Element Energy et al.: '*Analysis of fiscal incentives for $CO_2$-Enhanced Oil Recovery in the UK Continental Shelf*' (2013). An independent research project for the $CO_2$-EOR Joint Industry Project. The study quantified the impacts of a range of tax incentive structures, including dedicated field allowances, on the likelihood of investment by different oil companies at different oilfields.

**Gap**

Recent studies have identified a number of barriers to the development of $CO_2$ EOR in the UK. Technical barriers include:

- Matching $CO_2$ supply with demand in the short term (e.g. in relation to power station operations), medium term (e.g. maintenance schedules) and long term (e.g. storage capacity, lead times for offshore infrastructure and increased $CO_2$ recycling of mature $CO_2$ EOR projects).
- Missed opportunities from current decommissioning of oil fields.
- High project complexity and engineering challenges: a requirement for detailed modelling and infrastructure planning and long lead times with parallel but interdependent workstreams. Stakeholder networks required across diverse industries.

Financial and regulatory barriers include:

A high regulatory burden for $CO_2$ storage.

- A high level of complexity in clean power commercial arrangements.
- Fragile $CO_2$ EOR economics, long lead times, high finance rates and weak financial incentives.
- Shared equity ownership of oil fields creates potential commercial tension between partners.
- High oil taxation and complex tax environment:
  - boundaries between oil/gas tax regimes and CCS tax regimes have the potential to distort investment decisions (particularly with regard to decommissioning of infrastructure);
  - tax regime for individual fields can be non-transparent and a barrier to evaluation;
  - tax treatment of decommissioning and change of use arrangements adds complexity; and
  - currently no specific tax benefits available to $CO_2$-EOR and no industry consensus on preferred taxation structure.

**Identified next steps**

- Based on work in progress, create the case to treasury for a UK tax regime to support the development of brownfield $CO_2$ EOR projects in the North Sea **[CCSA]**.
- **[UK $CO_2$ Storage Development Group]** to consider potential synergies and cost benefit of $CO_2$ EOR with alternative storage solutions.

picture by Worley Parsons

# Conclusions 8

The Cost Reduction Task Force's objective was to examine the long-term outlook for generation costs from power stations that capture and store their carbon dioxide emissions. Many scenarios suggest that CCS power stations are likely to be a major component of the British decarbonisation targets for 2050. Indeed the flexibility of operation that gas- and coal-fired CCS power stations can offer may be essential in complementing the intermittent output of the wind generation fleet.

At this early stage of deployment, with even the few reference points of the costs of operation being largely based on technical studies rather than operation, this exercise has required members of the Task Force to use their experience to forecast the costs as the industry reaches maturity. Such an exercise has required:

- combining expertise from a technical point of view for the generation and capture part;
- understanding of the impact of developing a major infrastructure for the transport and storage part; as well as; and
- projecting the complex way in which commercial and financial arrangements grow from those appropriate to early projects those expected of a well-established industry.

With the collected experience of 30 members and contributors directly involved in all aspects of CCS project development, this Task Force is well-qualified to address the above issues.

### Having the right landscape…

It is clear from the previous sections of this Report that significant cost reductions are to be expected provided the right landscape engenders them.

Key components of the right landscape are as follows:

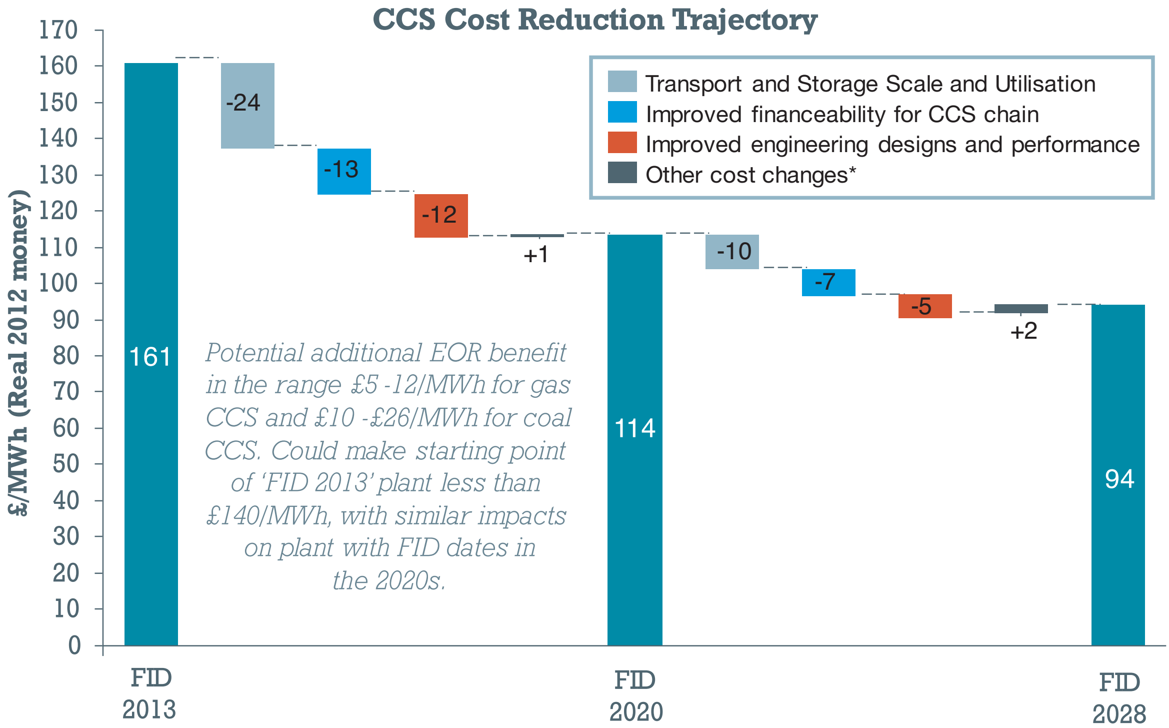
- Credible and long-term UK commitment to CCS by government and industry which includes a recognition of the role of CCS in the future generation mix, as well as a coordinated plan for transport and storage and an appropriate underpinning regulatory landscape;
- Multiple operating fullchain CCS plants that build on the current commercialisation programme; and
- Continued engagement with the financial sector, so that the industry and government jointly create access to low cost finance for CCS.

### …delivering the cost reductions

With this landscape in place, the overall cost reduction path for baseload CCS generation is shown in Figure 4, which translates the cost savings identified in Chapters 3, 4 and 5 – expressing them in terms of LCOE. For simplicity the diagram averages costs from the different technical approaches to capture, and takes as its starting point the baseline of a hypothetical full scale CCS-equipped power station reaching FID in 2013.

[20] Source: UKERC, 'Investment in electricity generation: the role of costs, incentives and risks', 2007

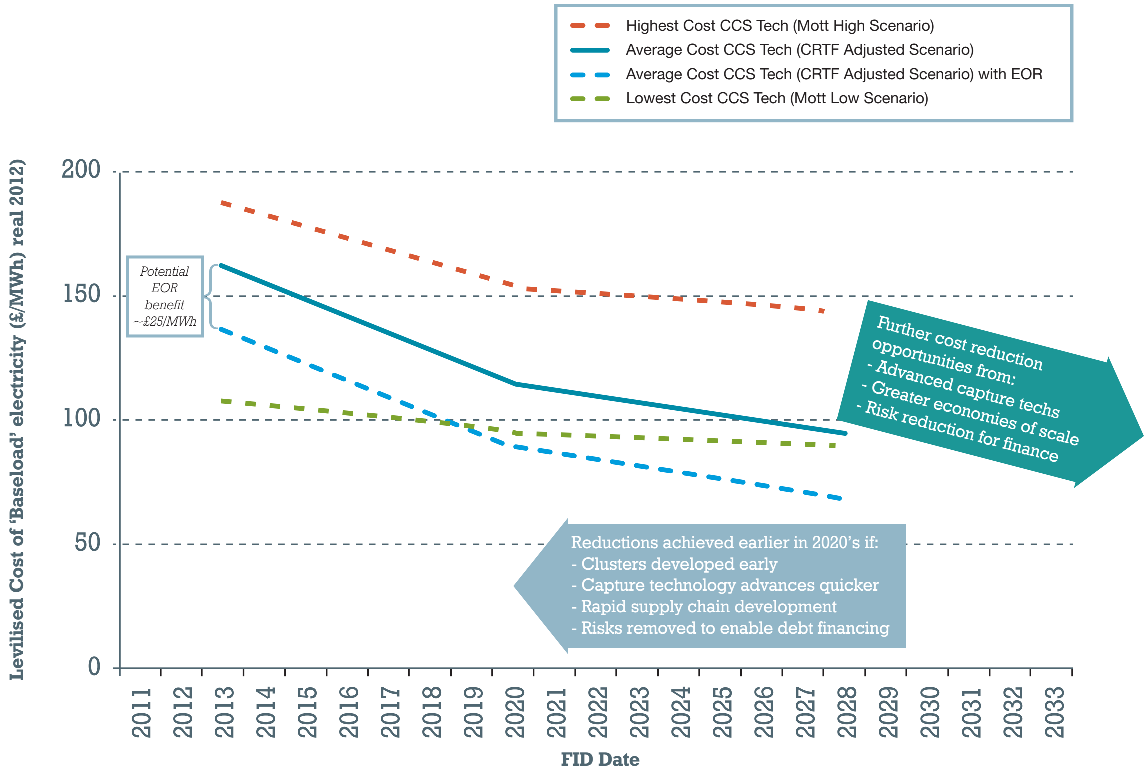
Figure 4 – Potential cost reduction mechanisms for CCS between plants reaching FID in 2013, 2020 and 2028 (technology average, 2012 £/MWh)




Note: Shows average costs across technologies. *E.G. Increasing $CO_2$ price, falling storage abandonment costs

If we take into account realistic ranges in both the overall costs of different technical approaches, and also in the range of cost reductions, we see a very significant downward trend. Figure 5 illustrates the trend for a baseload electricity station. The material potential for further reducing costs by incorporating $CO_2$ EOR projects is also shown in this diagram.

**Figure 5 – Range of cost reduction opportunities for CCS**




### …generating at costs comparable to other low carbon technologies

Several recent reports have suggested that offshore wind generation has the potential to reach LCOE of the order of £100/MWh, and this seems to be gradually being adopted as a benchmark for all lowcarbon technologies.

It is clear that Carbon Capture and Storage will be a direct economic competitor with more traditional 'renewables' – and even more so when its ability to back-up wind intermittency is taken into account.

### Key next steps…

It is by no means a given that these low cost levels will be reached: both Government and Industry will need to play their part, and while there are some clear policy gaps in the current CCS policy framework, industry has a significant contribution to make.

In this regard the Task Force identifies 32 next steps that that will be required in order to fully realise the opportunities for low cost competitive CCS in the UK. By initiating these Next Steps, the CRTF aspires to secure the formation of the appropriate 'CCS Landscape' which is favourable to the development of CCS projects and conducive to the cost reduction opportunities identified within the report. In particular, the Task Force highlights seven key next steps:

1. **Ensure optimal UK CCS transport and storage network configuration**

   Take into account likely future development of $CO_2$ storage hubs and the related pipeline networks. Conduct industry-led but government supported studies to identify options for developing configurations for the UK CCS transport and storage system for both early CCS projects and future CCS projects, in order to minimise long-run costs. (Led by UK $CO_2$ Storage Development Group.)

2. **Incentivise $CO_2$ EOR to limit emissions and maximise UK hydrocarbon production**

   Create a UK tax regime to support the development of brownfield $CO_2$ Enhanced Oil Recovery ($CO_2$ EOR) in the UK North Sea. (*Oil Companies, OCCS, DECC EDU.*)

3. **Ensure funding mechanisms are fit for purpose**

   Continue work to develop the coal and gas CfD structures, and other relevant EMR and funding instruments, ensuring their suitability for widespread use in coal and gas CCS projects. (*DECC, CCSA, UK CCS Commercial Development Group*)

4. **Create bankable contracts**

   Focus on how to construct contracts (including the detailed terms of CfDs) that will be needed to make follow-on projects bankable. This will include taking evidence from the published Commercialisation Programme ITPD, the experience of the Commercialisation Programme bidders and input from other stakeholder including finance and insurance sectors. (*UK CCS Commercial Development Group*)

5. **Create a vision for development of CCS projects in the UK from follow-on projects through to widespread adoption**

   Create an industry-led and government-supported vision of how subsequent phases of CCS projects in the UK can be developed and financed. The aim is to encourage and guide developers who are bringing the next UK CCS projects forward, which will get a CfD but no government grant. (*CCSA, The Crown Estate, DECC.*)

6. **Promote characterisation of $CO_2$ storage locations to create maximum benefit from the UK storage resource**

   Examine the options for characterisation of both storage areas and also specific sites for $CO_2$ storage in the UKCS, and recommend a way forward to Government and industry. The aim is to reduce the 'exploration risk' premium, thereby making storage sites bankable both commercially and technically. (*UK $CO_2$ Storage Development Group*)

7. **Create policy and financing regimes for CCS from industrial $CO_2$**

   Create proposed policy and financing regimes for the CCS of Industrial $CO_2$. (*BIS, CCSA and DECC.*)

**…new organisational structures**

To ensure the actions are delivered, the Task Force recommends the following national leadership groups be created to take forward the recommendations:

A. **The 'UK $CO_2$ Storage Development Group'.** This group will be led and co-ordinated by The Crown Estate. The aim of the group will be to unlock cost reductions through the benefits of scale and to reduce risks in the $CO_2$ storage and transport sector.

B. **The 'UK CCS Commercial Development Group'.** This group will involve active Bank and Insurance industry participants. The group will be established by CCSA, the Energy Technologies Institute, The Crown Estate and the Ecofin Foundation, and be led by the Ecofin Foundation. The aim of the group will be to secure ways, together with the UK Government, of making UK CCS projects bankable, and reducing their cost of capital.

B. **The UK CCS Knowledge Transfer Network.** This will be led by the CCSA. Its aim will be to enhance cost saving (and value enhancing) potential for CCS projects by promoting and facilitating the flow and review of knowledge and information, for both Industry and Government, following on from early projects in the UK and elsewhere. This will identify key gaps which stakeholders should address in order to ensure that CCS plays its full potential in the broader decarbonisation of the UK energy system.

**Still significant challenges ahead**

Through delivery of the next steps identified in this work, the CRTF endeavours to mitigate investor and operational risks and underpin successful development of follow-on and future UK CCS projects. The Task Force is confident that this future is possible.

# Annex A – Basis of modelling assumptions

The baseline agreed for this work is a derivative of estimated costs outlined in the DECC report by Mott MacDonald 2012. These costs were modelled in detail using the supporting information provided by Mott MacDonald.

Examining the 'Mott High' and 'Mott Low' scenarios, the opinions of the Task Force (on the sub-set of information contained in that model) were used to form a new baseline. This Baseline is titled the 'Cost Reduction Task Force Adjusted Path' and is referenced when discussing cost reduction opportunities, and their impacts, within this report.

## A.1 Summary of cost outputs for CRTF adjusted path

In general the cost assumptions made in the Mott Low Cost pathway were supported by the Task Force as achievable given the actions and recommendations in this report. The high cost pathway was regarded as representative of a world where the cost reduction opportunities presented here were not exploited (and was therefore not appropriate from the perspective of cost reduction opportunities).

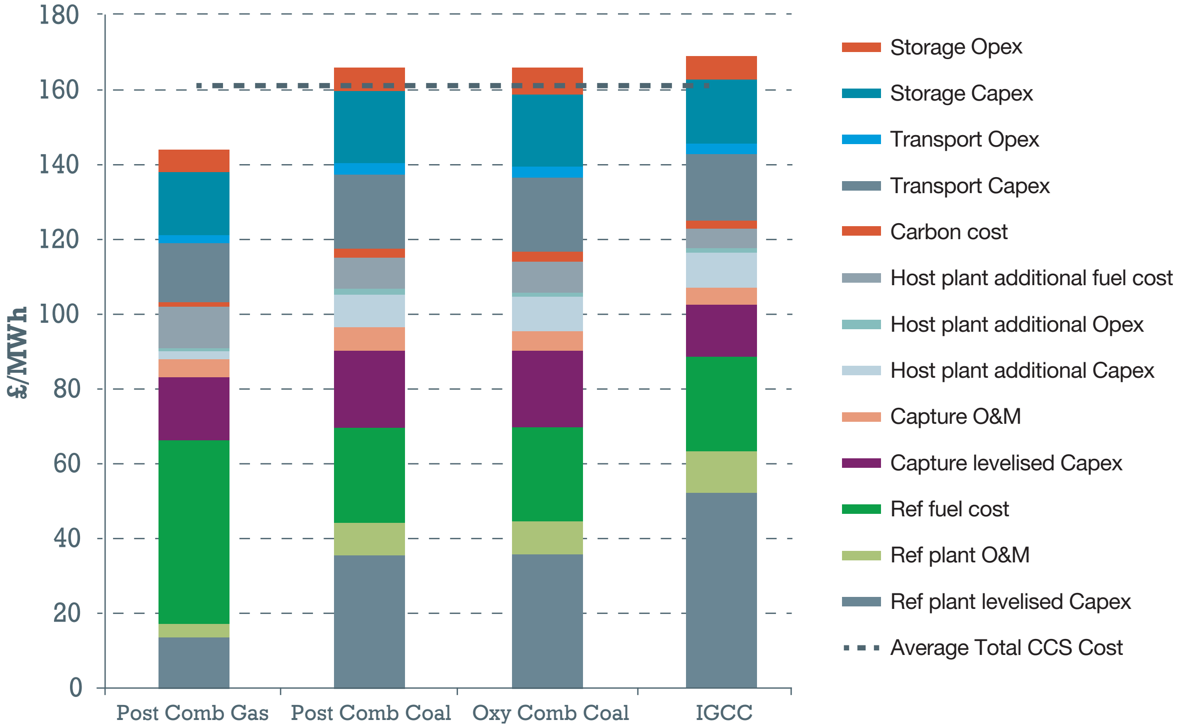
The following is a brief description of the plant types and CCS industry position from which the adjusted cost path was derived. Where aspects are highlighted in red they have been adjusted compared to the Mott MacDonald Low Cost Pathway. Fuel prices have been kept equal to those contained in the Mott MacDonald report (based on 2011 DECC central case) to ensure results are comparable. As with the Mott MacDonald work, the cost estimates include costs for a base (or host) plant and as such are focused on newly constructed CCS projects rather than the retrofit of CCS to existing power stations.

It should be recognised that the levelised cost of electricity from CCS will be partially driven by aspects unrelated to the cost reductions in this report. In particular these aspects include intentionally-driven commodity prices and, in some circumstances, the eventual load factor of the plants.

**A.1.1 2013**

- FID in 2013
- ~300MW net electrical output for both coal and gas plants, single projects
  - Not a specific design but using BAT technology
- Assumptions on all capex and opex from the Mott 2013 Low scenario
  - Host gas plant 54% HHV & £550/kW; Host post-comb coal plant 43% HHV & £1400/kW; Host oxy-comb coal plant 43% HHV & £1500/kW; IGCC 43% HHV & £2200/kW.
  - Energy penalty 25% for PC Coal & Oxy Coal, 17% for IGCC and 19% for PC Gas
- Plants capture 85% of the $CO_2$ produced and run at 80% load factor
- $CO_2$ transported 30km onshore and then 300km offshore in appropriate scale pipes (10'' for gas [1mtpa], 15'' for coal [2mtpa]) in dense phase and then stored in a DOGF
- We assume a 15 year economic lifetime for all components (inc. base plant, capture, transport and storage) with no terminal value
  - Shorter than standard due to the current lack of maturity of technology, assumed to increase to 25 years in the 2020s
- Pre-tax real Weighted Average Cost of Capital (WACC) assumption is 10% on the generation and capture, 10% on the transport pipeline infrastructure and 15% on the Storage
- Developer contingency included as a 10% uplift on all capital costs (supplier contingency is assumed to be contained in the capital cost estimates)

Figure 6 – LCOE of FID 2013 CCS technologies (£/MWh 2012 money)

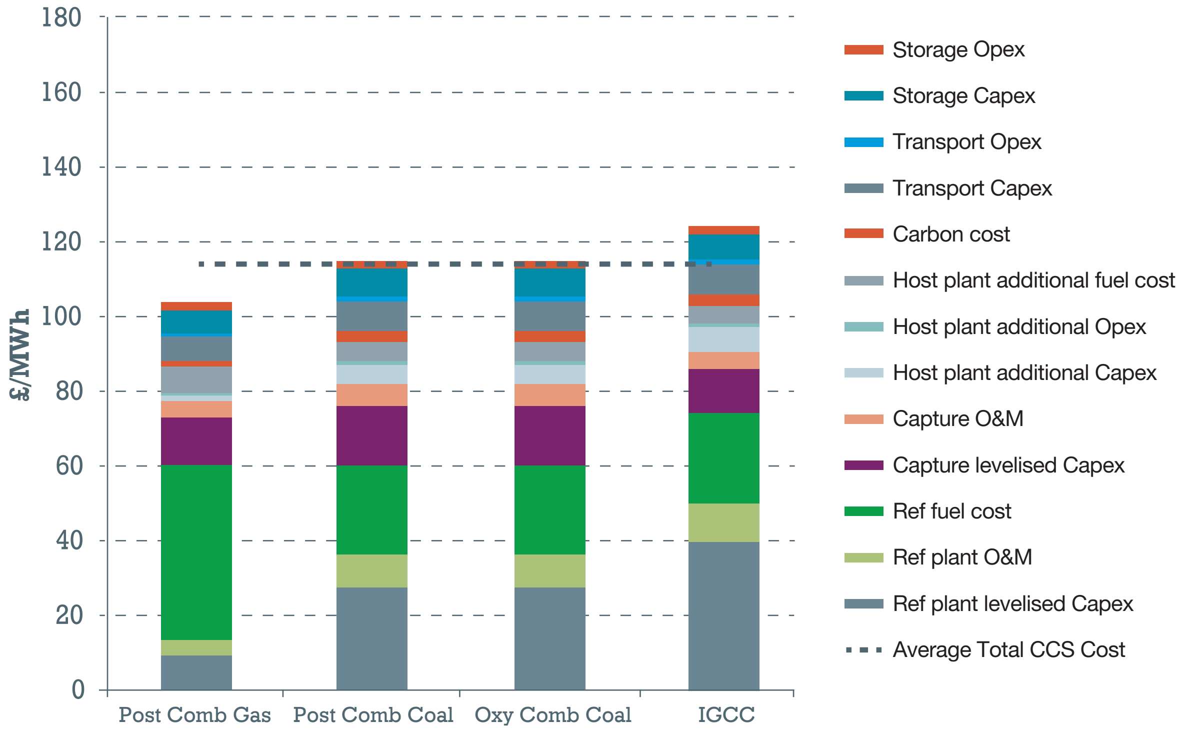



| £/MWh | Post Comb Gas | Post Comb Coal | Oxy Comb Coal | IGCC |
|---|---|---|---|---|
| **Ref plant levelised Capex** | 13.1 | 35.6 | 35.6 | 52.2 |
| **Ref plant O&M** | 4.2 | 8.9 | 8.9 | 11.1 |
| **Ref fuel cost** | 48.7 | 25.1 | 25.1 | 25.1 |
| **Capture levelised Capex** | 17.3 | 20.5 | 20.6 | 14.2 |
| **Host plant additional Capex** | 2.5 | 8.9 | 8.9 | 8.9 |
| **Host plant additional Opex** | 0.4 | 1.5 | 1.5 | 1.5 |
| **Capture O&M** | 4.9 | 6.4 | 5.4 | 4.9 |
| **Host plant additional fuel cost** | 11.4 | 8.4 | 8.4 | 5.1 |
| **Carbon cost** | 1.1 | 2.5 | 2.5 | 2.3 |
| **Transport Capex** | 15.8 | 20.0 | 20.0 | 18.1 |
| **Transport Opex** | 2.4 | 3.0 | 3.0 | 2.7 |
| **Storage Capex** | 16.8 | 19.2 | 19.2 | 17.3 |
| **Storage Opex** | 5.7 | 6.5 | 6.5 | 5.9 |
| **Total** | 144.1 | 166.5 | 165.6 | 169.3 |
| **Average Total CCS Cost** | **161.4** | **161.4** | **161.4** | **161.4** |

### A.1.2 2020

- FID in 2020
- ~800MW net electrical output for coal, ~600MW for gas, single projects
- Full commercial scale brings significant economies of scale benefits in capture, transport and storage
- Projects benefit from partial economies of scale in transport and storage but not yet part of large, well used clusters
- Not a specific design but using BAT technology
- Assumptions on all capex and opex from Mott 2020 Low (recognising potential range)
- Host gas plant 56% HHV & £500/kW; post-combustion coal plant 45% HHV & £1400/kW; oxyfuel coal plant 45% HHV & £1400/kW ; IGCC 45% HHV & £2000/kW
- Energy penalty 18% for PC Coal & Oxy Coal, 16% for IGCC and 14% for PC Gas
- Plants capture 90% of the $CO_2$ produced and run at 80% load factor
- $CO_2$ transported 40km onshore and then 300km offshore in appropriately scaled pipes (15'' for gas [2mtpa], 18'' for coal [4mtpa]) in dense phase and then stored in a DOGF
- We assume a 25 year economic lifetime for all components (inc. base plant, capture, transport and storage) with no terminal value
- Pre-tax real WACC assumption is 10% on the generation and capture, 10% on the transport pipeline infrastructure and 14% on the Storage
  - 1% lower than 2013 as risk perception lowered on storage component (still 4% higher than Mott Low Cost path assumption)
- Developer contingency included as a 10% uplift on all capital costs (supplier contingency is assumed to be contained in the capital cost estimates).

Figure 7 – LCOE of FID 2020 CCS technologies (£/MWh 2012 money)

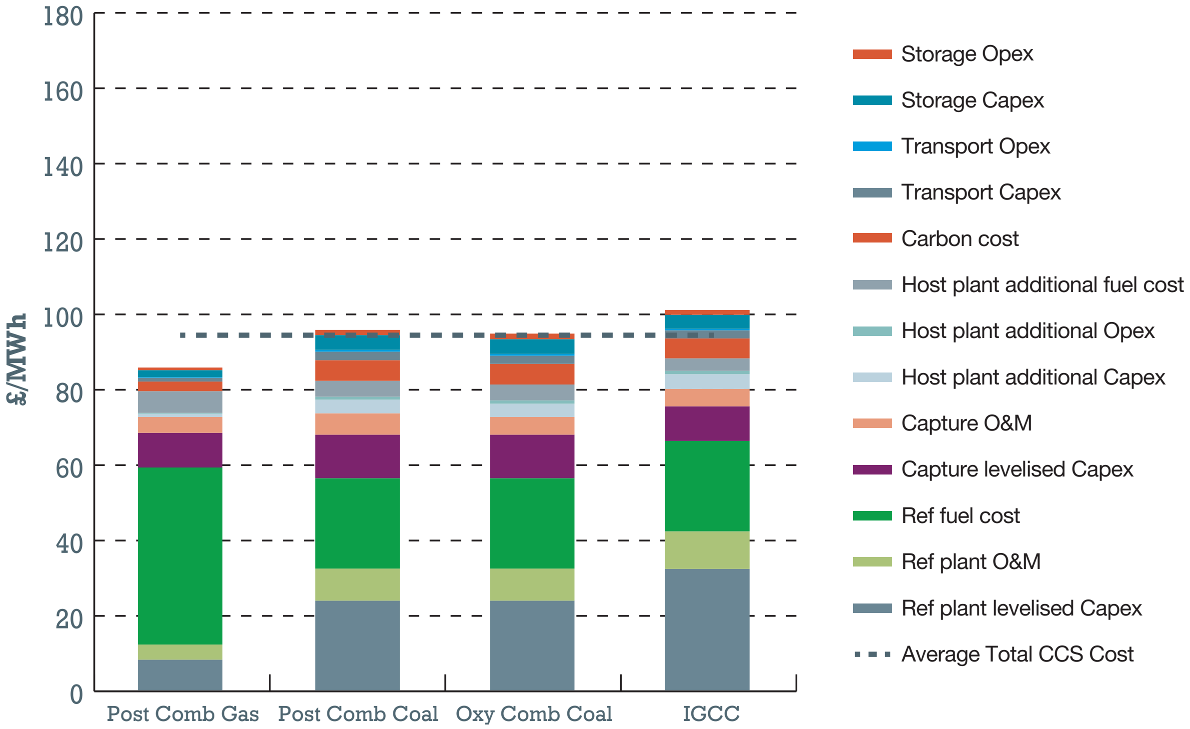


| £/MWh | Post Comb Gas | Post Comb Coal | Oxy Comb Coal | IGCC |
|---|---|---|---|---|
| **Ref plant levelised Capex** | 9.5 | 27.8 | 27.8 | 39.8 |
| **Ref plant O&M** | 4.0 | 8.5 | 8.5 | 10.3 |
| **Ref fuel cost** | 46.9 | 24.0 | 24.0 | 24.0 |
| **Capture levelised Capex** | 12.5 | 15.5 | 15.6 | 11.7 |
| **Host plant additional Capex** | 1.3 | 5.0 | 5.0 | 6.4 |
| **Host plant additional Opex** | 0.3 | 1.0 | 1.0 | 1.3 |
| **Capture O&M** | 4.6 | 6.1 | 5.1 | 4.8 |
| **Host plant additional fuel cost** | 7.6 | 5.3 | 5.3 | 4.6 |
| **Carbon cost** | 1.3 | 2.8 | 2.8 | 2.7 |
| **Transport Capex** | 6.4 | 8.3 | 8.3 | 8.1 |
| **Transport Opex** | 1.2 | 1.5 | 1.5 | 1.5 |
| **Storage Capex** | 6.0 | 6.7 | 6.7 | 6.5 |
| **Storage Opex** | 2.1 | 2.3 | 2.3 | 2.2 |
| **Total** | 103.7 | 114.7 | 113.9 | 123.8 |
| **Average Total CCS Cost** | **114.0** | **114.0** | **114.0** | **114.0** |

A.1.3 2028

- FID in 2028
- ~800MW+ net electrical output for coal, ~600MW+ for gas
  - Clusters allow for higher $CO_2$ flow than from the single station – 15mpta through the network
- Not a specific design but using BAT technology
- Assumptions on all capex and opex from Mott 2028 Low figures
- Host gas plant 56% HHV & £500/kW; post-combustion coal plant 45% HHV & £1400/kW; oxyfuel coal plant 45% HHV & £1400/kW ; IGCC 45% HHV & £1900/kW
- Energy penalty 15% for PC Coal & Oxy Coal, 12% for IGCC and 11% for PC Gas
- Plants capture 90% of the $CO_2$ produced and run at 80% load factor
- $CO_2$ transported 40 km onshore and then 300km offshore in appropriate scale pipes (36'' for both gas and coal - 15mtpa) in dense phase and then stored in a DOGF
- We assume a 25 year economic lifetime for all components (inc. base plant, capture, transport and storage) with no terminal value
- Pre-tax real WACC assumption is 8% on the generation and capture, 8% on the transport pipeline infrastructure and 12% on the Storage
  - Fall of 2-3% from 2013 as some risk has been removed from due to 'landscape' actions and project finance is now available for at least certain aspects. Storage WACC still 2% higher than Mott assumption.
- Developer contingency included as a 10% uplift on all capital costs (supplier contingency is assumed to be contained in the capital cost estimates).

Figure 8 – LCOE of FID 2028 CCS technologies (£/MWh 2012 money)




| £/MWh | Post Comb Gas | Post Comb Coal | Oxy Comb Coal | IGCC |
|---|---|---|---|---|
| **Ref plant levelised Capex** | 8.1 | 23.7 | 23.7 | 32.1 |
| **Ref plant O&M** | 4.0 | 8.5 | 8.5 | 10.0 |
| **Ref fuel cost** | 46.9 | 24.0 | 24.0 | 24.0 |
| **Capture levelised Capex** | 9.2 | 11.5 | 11.4 | 9.3 |
| **Host plant additional Capex** | 0.9 | 3.6 | 3.6 | 3.9 |
| **Host plant additional Opex** | 0.2 | 0.8 | 0.8 | 0.9 |
| **Capture O&M** | 4.2 | 5.7 | 4.7 | 4.6 |
| **Host plant additional fuel cost** | 5.8 | 4.2 | 4.2 | 3.3 |
| **Carbon cost** | 2.5 | 5.5 | 5.5 | 5.3 |
| **Transport Capex** | 1.0 | 2.2 | 2.2 | 2.1 |
| **Transport Opex** | 0.2 | 0.5 | 0.5 | 0.4 |
| **Storage Capex** | 1.9 | 3.9 | 3.9 | 3.7 |
| **Storage Opex** | 0.6 | 1.4 | 1.4 | 1.3 |
| **Total** | 85.6 | 95.3 | 94.2 | 100.8 |
| **Average Total CCS Cost** | **94.0** | **94.0** | **94.0** | **94.0** |

# A.2 Generation and capture assumptions

## A.2.1 Post-combustion coal

| Post Combustion Coal | | | Low cost path | | | | High cost path | | | | Adjusted path | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | 2013 | 2020 | 2028 | 2040 | 2013 | 2020 | 2028 | 2040 | 2013 | 2020 | 2028 |
| Capture | ACF | % | 80% | 80% | 80% | 80% | 60% | 60% | 60% | 60% | 80% | 80% | 80% |
| Capture | WACC | % | 10% | 10% | 10% | 10% | 10% | 10% | 10% | 10% | 10% | 10% | 8% |
| Capture | Plant life Years | 15 | 30 | 30 | 30 | 15 | 20 | 25 | 30 | 15 | 25 | 25 | |
| Capture | Energy penalty | % | 25% | 23% | 18% | 13% | 26% | 24% | 22% | 18% | 25% | 18% | 15% |
| Both | Energy cost | £/GJ | 3.00 | 3.00 | 3.00 | 3.00 | 3.00 | 3.00 | 3.00 | 3.00 | 3.00 | 3.00 | 3.00 |
| Capture | Tech. component: Dev.etc | £/kW | 67 | 63 | 60 | 57 | 77 | 77 | 74 | 71 | 67 | 63 | 60 |
| Capture | Tech. component: Absorbers | £/kW | 350 | 304 | 256 | 226 | 403 | 398 | 375 | 353 | 350 | 304 | 256 |
| Capture | Tech. component: Regen. | £/kW | 125 | 113 | 97 | 88 | 144 | 141 | 133 | 127 | 125 | 113 | 97 |
| Capture | Tech. component: Compres. | £/kW | 216 | 203 | 180 | 158 | 248 | 239 | 229 | 220 | 216 | 203 | 180 |
| Capture | Tech. component: Host plant | £/kW | 375 | 322 | 252 | 182 | 442 | 384 | 352 | 288 | 375 | 322 | 252 |
| Capture | Tech. component: BoP | £/kW | 108 | 98 | 87 | 77 | 124 | 123 | 118 | 111 | 108 | 98 | 87 |
| Capture | VOM (CCS) | % capex | 3.00 | 3.00 | 3.00 | 3.00 | 4.00 | 4.00 | 4.00 | 4.00 | 3.00 | 3.00 | 3.00 |
| Ref | Specific Capex (Ref Plant) | £/kW | 1500 | 1400 | 1400 | 1400 | 1700 | 1600 | 1600 | 1600 | 1500 | 1400 | 1400 |
| Ref | ACF (Ref Plant) | % | 80% | 80% | 80% | 80% | 60% | 60% | 60% | 60% | 80% | 80% | 80% |
| Ref | WACC (Ref Plant) | % | 10% | 10% | 10% | 10% | 10% | 10% | 10% | 10% | 10% | 10% | 8% |
| Ref | Plant life (Ref Plant) | Years | 30 | 30 | 30 | 30 | 25 | 25 | 25 | 30 | 15 | 25 | 25 |
| Ref | VOM (Ref Plant) | % capex | 3.0 | 3.0 | 3.0 | 3.0 | 4.0 | 4.0 | 4.0 | 4.0 | 3.0 | 3.0 | 3.0 |
| Both | Carbon cost | £/tCO2 | 16 | 30 | 62 | 110 | 16 | 30 | 62 | 110 | 16 | 30 | 62 |
| Both | % Carbon stored | % | 85% | 85% | 85% | 85% | 85% | 85% | 85% | 85% | 85% | 90% | 90% |
| Both | Implied IDC % | % | 15% | 15% | 15% | 15% | 15% | 15% | 15% | 15% | 15% | 15% | 15% |
| Both | $CO_2$ content of fuel | tCO2/tFuel | 0.341 | 0.341 | 0.341 | 0.341 | 0.341 | 0.341 | 0.341 | 0.341 | 0.341 | 0.341 | 0.341 |
| Capture | Efficiency of plant (CCS) | % | 30% | 31% | 33% | 35% | 30% | 30% | 31% | 33% | 32% | 37% | 38% |
| Ref | Efficiency of plant (Ref) | % | 40% | 40% | 40% | 40% | 40% | 40% | 40% | 40% | 43% | 45% | 45% |
| Both | FOM % | % | 2.5% | 2.5% | 2.5% | 2.5% | 2.5% | 2.5% | 2.5% | 2.5% | 2.5% | 2.5% | 2.5% |
| All (inc. T&S) | Developer contingency | % | 0% | 0% | 0% | 0% | 0% | 0% | 0% | 0% | 10% | 10% | 10% |

### A.2.2 Post-combustion gas

| Post Combustion Gas | | | Low cost path | | | | High cost path | | | | Adjusted path | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | 2013 | 2020 | 2028 | 2040 | 2013 | 2020 | 2028 | 2040 | 2013 | 2020 | 2028 |
| Capture | ACF | % | 80% | 80% | 80% | 80% | 60% | 60% | 60% | 60% | 80% | 80% | 80% |
| Capture | WACC | % | 10% | 10% | 10% | 10% | 10% | 10% | 10% | 10% | 10% | 10% | 8% |
| Capture | Plant life | Years | 15 | 30 | 30 | 30 | 15 | 20 | 25 | 30 | 15 | 25 | 25 |
| Capture | Energy penalty | % | 15% | 14% | 11% | 7% | 16% | 15% | 13% | 10% | 19% | 14% | 11% |
| Both | Energy cost | £/GJ | 7.30 | 7.30 | 7.30 | 7.30 | 7.30 | 7.30 | 7.30 | 7.30 | 7.30 | 7.30 | 7.30 |
| Capture | Tech. component: Dev.etc | £/kW | 55 | 52 | 50 | 47 | 66 | 66 | 64 | 61 | 55 | 52 | 50 |
| Capture | Tech. component: Absorbers | £/kW | 310 | 269 | 226 | 200 | 372 | 368 | 347 | 326 | 310 | 269 | 226 |
| Capture | Tech. component: Regen. £/kW | 120 | 108 | 93 | 84 | 144 | 141 | 133 | 128 | 120 | 108 | 93 | 97 |
| Capture | Tech. component: Compres. | £/kW | 150 | 141 | 125 | 110 | 180 | 173 | 166 | 160 | 150 | 141 | 125 |
| Capture | Tech. component: Host plant | £/kW | 83 | 70 | 55 | 35 | 88 | 83 | 72 | 55 | 83 | 70 | 55 |
| Capture | Tech. component: BoP | £/kW | 95 | 86 | 77 | 67 | 114 | 113 | 108 | 102 | 95 | 86 | 77 |
| Capture | VOM (CCS) | % capex | 2.00 | 2.00 | 2.00 | 2.00 | 3.00 | 3.00 | 3.00 | 3.00 | 2.00 | 2.00 | 2.00 |
| Ref | Specific Capex (Ref Plant) | £/kW | 550 | 500 | 500 | 500 | 550 | 550 | 550 | 550 | 550 | 500 | 500 |
| Ref | ACF (Ref Plant) | % | 80% | 80% | 80% | 80% | 60% | 60% | 60% | 60% | 80% | 80% | 80% |
| Ref | WACC (Ref Plant) | % | 10% | 10% | 10% | 10% | 10% | 10% | 10% | 10% | 10% | 10% | 8% |
| Ref | Plant life (Ref Plant) | Years | 25 | 30 | 30 | 30 | 20 | 20 | 25 | 30 | 15 | 25 | 25 |
| Ref | VOM (Ref Plant) | % capex | 2.0 | 2.0 | 2.0 | 2.0 | 3.0 | 3.0 | 3.0 | 3.0 | 2.0 | 2.0 | 2.0 |
| Both | Carbon cost | £/tCO2 | 16 | 30 | 62 | 110 | 16 | 30 | 62 | 110 | 16 | 30 | 62 |
| Both | % Carbon stored | % | 85% | 85% | 85% | 85% | 85% | 85% | 85% | 85% | 85% | 90% | 90% |
| Both | Implied IDC % | % | 10% | 10% | 10% | 10% | 10% | 10% | 10% | 10% | 15% | 10% | 10% |
| Both | $CO_2$ content of fuel | tCO2/tFuel | 0.202 | 0.202 | 0.202 | 0.202 | 0.202 | 0.202 | 0.202 | 0.202 | 0.202 | 0.202 | 0.202 |
| Capture | Efficiency of plant (CCS) | % | 46% | 46% | 48% | 50% | 45% | 45% | 46% | 48% | 44% | 48% | 50% |
| Ref | Efficiency of plant (Ref) | % | 54% | 54% | 54% | 54% | 53% | 53% | 53% | 53% | 54% | 56% | 56% |
| Both | FOM % % | 2.5% | 2.5% | 2.5% | 2.5% | 2.5% | 2.5% | 2.5% | 2.5% | 2.5% | 2.5% | 2.5% | 2.5% |
| All (inc. T&S) | Developer contingency | % | 0% | 0% | 0% | 0% | 0% | 0% | 0% | 0% | 10% | 10% | 10% |

### A.2.3 Oxyfuel combustion coal

| Oxy-Combustion Coal | | | Low cost path | | | | High cost path | | | | Adjusted path | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | 2013 | 2020 | 2028 | 2040 | 2013 | 2020 | 2028 | 2040 | 2013 | 2020 | 2028 |
| Capture | ACF | % | 80% | 80% | 80% | 80% | 60% | 60% | 60% | 60% | 80% | 80% | 80% |
| Capture | WACC | % | 10% | 10% | 10% | 10% | 10% | 10% | 10% | 10% | 10% | 10% | 8% |
| Capture | Plant life | Years | 15 | 30 | 30 | 30 | 15 | 20 | 25 | 30 | 15 | 25 | 25 |
| Capture | Energy penalty | % | 25% | 22% | 16% | 11% | 26% | 24% | 21% | 17% | 25% | 18% | 15% |
| Both | Energy cost | £/GJ | 3.00 | 3.00 | 3.00 | 3.00 | 3.00 | 3.00 | 3.00 | 3.00 | 3.00 | 3.00 | 3.00 |
| Capture | Tech. component: Dev.etc | £/kW | 67 | 63 | 60 | 57 | 80 | 80 | 78 | 74 | 67 | 63 | 60 |
| Capture | Tech. component: Air Sep. | £/kW | 280 | 243 | 200 | 177 | 336 | 329 | 301 | 283 | 280 | 243 | 200 |
| Capture | Tech. component: Conditioning | £/kW | 200 | 181 | 152 | 136 | 240 | 233 | 213 | 204 | 200 | 181 | 152 |
| Capture | Tech. component: Compres. | £/kW | 216 | 203 | 176 | 155 | 259 | 246 | 237 | 227 | 216 | 203 | 176 |
| Capture | Tech. component: Host plant | £/kW | 375 | 308 | 224 | 154 | 442 | 384 | 336 | 272 | 375 | 308 | 224 |
| Capture | Tech. component: BoP | £/kW | 107 | 97 | 87 | 76 | 128 | 127 | 122 | 115 | 107 | 97 | 87 |
| Capture | VOM (CCS) | % capex | 2.00 | 2.00 | 2.00 | 2.00 | 3.00 | 3.00 | 3.00 | 3.00 | 2.00 | 2.00 | 2.00 |
| Ref | Specific Capex (Ref Plant) | £/kW | 1500 | 1400 | 1400 | 1400 | 1700 | 1600 | 1600 | 1600 | 1500 | 1400 | 1400 |
| Ref | ACF (Ref Plant) | % | 80% | 80% | 80% | 80% | 60% | 60% | 60% | 60% | 80% | 80% | 80% |
| Ref | WACC (Ref Plant) | % | 10% | 10% | 10% | 10% | 10% | 10% | 10% | 10% | 10% | 10% | 8% |
| Ref | Plant life (Ref Plant) | Years | 30 | 30 | 30 | 30 | 25 | 25 | 25 | 30 | 15 | 25 | 25 |
| Ref | VOM (Ref Plant) | % capex | 3.0 | 3.0 | 3.0 | 3.0 | 4.0 | 4.0 | 4.0 | 4.0 | 3.0 | 3.0 | 3.0 |
| Both | Carbon cost | £/tCO2 | 16 | 30 | 62 | 110 | 16 | 30 | 62 | 110 | 16 | 30 | 62 |
| Both | % Carbon stored | % | 85% | 85% | 85% | 85% | 85% | 85% | 85% | 85% | 85% | 90% | 90% |
| Both | Implied IDC % | % | 15% | 15% | 15% | 15% | 15% | 15% | 15% | 15% | 15% | 15% | 15% |
| Both | $CO_2$ content of fuel | tCO2/tFuel | 0.341 | 0.341 | 0.341 | 0.341 | 0.341 | 0.341 | 0.341 | 0.341 | 0.341 | 0.341 | 0.341 |
| Capture | Efficiency of plant (CCS) | % | 30% | 31% | 34% | 36% | 30% | 30% | 32% | 33% | 32% | 37% | 38% |
| Ref | Efficiency of plant (Ref) | % | 40% | 40% | 40% | 40% | 40% | 40% | 40% | 40% | 43% | 45% | 45% |
| Both | FOM % | % | 2.5% | 2.5% | 2.5% | 2.5% | 2.5% | 2.5% | 2.5% | 2.5% | 2.5% | 2.5% | 2.5% |
| All (inc. T&S) | Developer contingency | % | 0% | 0% | 0% | 0% | 0% | 0% | 0% | 0% | 10% | 10% | 10% |

### A.2.4 IGCC

| IGCC | | | Low cost path | | | | High cost path | | | | Adjusted path | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | 2013 | 2020 | 2028 | 2040 | 2013 | 2020 | 2028 | 2040 | 2013 | 2020 | 2028 |
| Capture | ACF | % | 80% | 75% | 70% | 65% | 60% | 55% | 50% | 45% | 80% | 80% | 80% |
| Capture | WACC | % | 10% | 10% | 10% | 10% | 10% | 10% | 10% | 10% | 10% | 10% | 8% |
| Capture | Plant life | Years | 15 | 30 | 30 | 30 | 15 | 20 | 25 | 30 | 15 | 25 | 25 |
| Capture | Energy penalty | % | 17% | 16% | 12% | 10% | 20% | 19% | 17% | 15% | 17% | 16% | 12% |
| Both | Energy cost | £/GJ | 3.00 | 3.00 | 3.00 | 3.00 | 3.00 | 3.00 | 3.00 | 3.00 | 3.00 | 3.00 | 3.00 |
| Capture | Tech. component: Dev.etc | £/kW | 60 | 59 | 58 | 56 | 72 | 72 | 71 | 71 | 60 | 59 | 58 |
| Capture | Tech. component: Water shift | £/kW | 200 | 198 | 183 | 165 | 240 | 242 | 242 | 238 | 200 | 198 | 183 |
| Capture | Tech. component: Conditioning | £/kW | 160 | 155 | 140 | 131 | 192 | 192 | 192 | 188 | 160 | 155 | 140 |
| Capture | Tech. component: Compres. | £/kW | 80 | 78 | 72 | 65 | 96 | 94 | 94 | 94 | 80 | 78 | 72 |
| Capture | Tech. component: Host plant | £/kW | 374 | 320 | 228 | 180 | 500 | 456 | 391 | 330 | 374 | 320 | 228 |
| Capture | Tech. component: BoP | £/kW | 100 | 96 | 90 | 83 | 120 | 121 | 119 | 119 | 100 | 96 | 90 |
| Capture | VOM (CCS) | % capex | 2.50 | 2.50 | 2.50 | 2.50 | 3.00 | 3.00 | 3.00 | 3.00 | 2.50 | 2.50 | 2.50 |
| Ref | Specific Capex (Ref Plant) | £/kW | 2200 | 2000 | 1900 | 1800 | 2500 | 2400 | 2300 | 2200 | 2200 | 2000 | 1900 |
| Ref | ACF (Ref Plant) | % | 80% | 80% | 80% | 80% | 60% | 60% | 60% | 60% | 80% | 80% | 80% |
| Ref | WACC (Ref Plant) | % | 10% | 10% | 10% | 10% | 10% | 10% | 10% | 10% | 10% | 10% | 8% |
| Ref | Plant life (Ref Plant) | Years | 30 | 30 | 30 | 30 | 20 | 20 | 25 | 30 | 15 | 25 | 25 |
| Ref | VOM (Ref Plant) | % capex | 2.5 | 2.5 | 2.5 | 2.5 | 3.0 | 3.0 | 3.0 | 3.0 | 2.5 | 2.5 | 2.5 |
| Both | Carbon cost | £/tCO2 | 16 | 30 | 62 | 110 | 16 | 30 | 62 | 110 | 16 | 30 | 62 |
| Both | % Carbon stored | % | 85% | 85% | 85% | 85% | 85% | 85% | 85% | 85% | 85% | 90% | 90% |
| Both | Implied IDC % | % | 15% | 15% | 15% | 15% | 15% | 15% | 15% | 15% | 15% | 15% | 15% |
| Both | $CO_2$ content of fuel | tCO2/tFuel | 0.341 | 0.341 | 0.341 | 0.341 | 0.341 | 0.341 | 0.341 | 0.341 | 0.341 | 0.341 | 0.341 |
| Capture | Efficiency of plant (CCS) | % | 33% | 34% | 35% | 36% | 32% | 32% | 33% | 34% | 36% | 38% | 40% |
| Ref | Efficiency of plant | (Ref) % | 40% | 40% | 40% | 40% | 40% | 40% | 40% | 40% | 43% | 45% | 45% |
| Both | FOM % | % | 2.5% | 2.5% | 2.5% | 2.5% | 2.5% | 2.5% | 2.5% | 2.5% | 2.5% | 2.5% | 2.5% |
| All (inc. T&S) | Developer contingency | % | 0% | 0% | 0% | 0% | 0% | 0% | 0% | 0% | 10% | 10% | 10% |

### A.3 Transport assumptions

Transport capital and operational cost assumptions have been taken from the Mott MacDonald report. Only minor adjustments have been made for the CRTF adjusted scenario at this point, largely regarding the assumed throughput of $CO_2$ and pipeline diameters in FID 2013 and 2020 gas projects. The amortisation rate and period applied to the capital expenditure has also been adjusted to better reflect Task Force estimates. It should be recognised that the simplified approach taken in these kinds of LCOE calculations can only partially reflect real-world financial arrangements.

| Common assumptions | | | 2013 | 2020 | 2028 | 2040 |
|---|---|---|---|---|---|---|
| **Subsea** | Subsea Capex 10" | £/km | 0.77 | 0.69 | 0.66 | 0.63 |
| **Subsea** | Subsea Capex 15" | £/km | 0.85 | 0.77 | 0.73 | 0.69 |
| **Subsea** | Subsea Capex 18" | £/km | 1.00 | 0.90 | 0.86 | 0.81 |
| **Subsea** | Subsea Capex 36" | £/km | 1.25 | 1.13 | 1.07 | 1.02 |
| **Subsea** | Subsea Opex % | % | 2.0% | 2.0% | 2.0% | 2.0% |
| **Subsea & onshore** | Throughput 10" | mtpa | 1 | 1 | 1 | 1 |
| **Subsea & onshore** | Throughput 15" | mtpa | 2 | 2 | 2 | 3 |
| **Subsea & onshore** | Throughput 18" | mtpa | 2 | 4 | 4 | 5 |
| **Subsea & onshore** | Throughput 36" | mtpa | 2 | 10 | 15 | 18 |
| **Onshore** | Onshore Capex 10" | £/km | 0.39 | 0.35 | 0.33 | 0.31 |
| **Onshore** | Onshore Capex 15" | £/km | 0.43 | 0.38 | 0.36 | 0.35 |
| **Onshore** | Onshore Capex 18" | £/km | 0.50 | 0.45 | 0.43 | 0.41 |
| **Onshore** | Onshore Capex 36" | £/km | 0.63 | 0.56 | 0.53 | 0.51 |
| **Onshore** | Onshore opex % | % | 1.5% | 1.5% | 1.5% | 1.5% |

| Pipe diameters | | | 2013 | 2020 | 2028 | 2040 |
|---|---|---|---|---|---|---|
| **Subsea** | Low gas subsea pipe diameter | " | 15 | 18 | 36 | 36 |
| **Subsea** | High gas subsea pipe diameter | " | 10 | 15 | 15 | 15 |
| **Subsea** | Adjusted gas subsea pipe diameter | " | 10 | 15 | 36 | |
| **Subsea** | Low coal subsea pipe diameter | " | 15 | 18 | 36 | 36 |
| **Subsea** | High coal subsea pipe diameter | " | 10 | 15 | 15 | 15 |
| **Subsea** | Adjusted coal subsea pipe diameter | " | 15 | 18 | 36 | |
| **Onshore** | Low gas onshore pipe diameter | " | 15 | 18 | 36 | 36 |
| **Onshore** | High gas onshore pipe diameter | " | 10 | 15 | 15 | 15 |
| **Onshore** | Adjusted gas onshore pipe diameter | " | 10 | 15 | 36 | |
| **Onshore** | Low coal onshore pipe diameter | " | 15 | 18 | 36 | 36 |
| **Onshore** | High coal onshore pipe diameter | " | 10 | 15 | 15 | 15 |
| **Onshore** | Adjusted coal onshore pipe diameter | " | 15 | 18 | 36 | |

| Amortisation life | | | 2013 | 2020 | 2028 | 2040 |
|---|---|---|---|---|---|---|
| Subsea & onshore | Low gas amortisation life (onshore & offshore) | years | 25 | 30 | 35 | 40 |
| Subsea & onshore | High gas amortisation life (onshore & offshore) | years | 25 | 30 | 35 | 40 |
| Subsea & onshore | Adjusted gas amortisation life (onshore & offshore) | years | 15 | 25 | 25 | |
| Subsea & onshore | Low coal amortisation life (onshore & offshore) | years | 25 | 30 | 35 | 40 |
| Subsea & onshore | High coal amortisation life (onshore & offshore) | years | 25 | 30 | 35 | 40 |
| Subsea & onshore | Adjusted coal amortisation life (onshore & offshore) | years | 15 | 25 | 25 | |

| PMT rate | | | 2013 | 2020 | 2028 | 2040 |
|---|---|---|---|---|---|---|
| Subsea & onshore | Low gas PMT rate (onshore & offshore) | % | 10% | 10% | 10% | 10% |
| Subsea & onshore | High gas PMT rate (onshore & offshore) | % | 10% | 10% | 10% | 10% |
| Subsea & onshore | Adjusted gas PMT rate (onshore & offshore) | % | 10% | 10% | 8% | |
| Subsea & onshore | Low coal PMT rate (onshore & offshore) | % | 10% | 10% | 10% | 10% |
| Subsea & onshore | High coal PMT rate (onshore & offshore) | % | 10% | 10% | 10% | 10% |
| Subsea & onshore | Adjusted coal PMT rate (onshore & offshore) | % | 10% | 10% | 8% | |

| Average pipe lengths | | | 2013 | 2020 | 2028 | 2040 |
|---|---|---|---|---|---|---|
| Onshore | Low gas onshore pipe length | km | 30 | 50 | 80 | 80 |
| Onshore | High gas onshore pipe length | km | 30 | 30 | 30 | 30 |
| Onshore | Adjusted gas onshore pipe length | km | 30 | 40 | 40 | |
| Onshore | Low coal onshore pipe length | km | 30 | 50 | 80 | 80 |
| Onshore | High coal onshore pipe length | km | 30 | 30 | 30 | 30 |
| Onshore | Adjusted coal onshore pipe length | km | 30 | 40 | 40 | |
| Subsea | Subsea pipe length | km | 300 | 300 | 300 | 300 |

### A.4 Storage assumptions

Storage capital and operational cost assumptions have been taken from Mott Macdonald report. Only minor adjustments have been made for the CRTF adjusted scenario at this point, largely regarding the assumed throughput of CO2 in FID 2013 and 2020 projects and the amortisation rate and period applied to the capital expenditure (labelled as PMT rate below).

| DOGF: Low path coal | | 2013 | 2020 | 2028 | 2040 |
|---|---|---|---|---|---|
| Pre-FID | £m | 19.20 | 19.20 | 19.20 | 19.20 |
| Pipelines | £m | 6.00 | 5.36 | 4.54 | 3.86 |
| Platforms | £m | 124.00 | 110.84 | 93.86 | 79.70 |
| Wells | £m | 41.00 | 36.65 | 31.03 | 25.56 |
| MMV | £m | 0.00 | 0.00 | 0.00 | 0.00 |
| Abandonment | £m | 75.00 | 58.93 | 46.30 | 37.25 |
| Throughput $CO_2$ | mtpa | 2 | 4 | 5 | 5 |
| Amortisation period | years | 20 | 25 | 30 | 35 |
| Annual OPEX% | % | 6.0% | 5.0% | 4.5% | 4.0% |
| PMT rate | % | 10% | 10% | 10% | 10% |
| IDC % | % | 15% | 15% | 15% | 15% |

| DOGF: Low path gas | 2013 | 2020 | 2028 | 2040 |
|---|---|---|---|---|
| Pre-FID | 19.20 | 19.20 | 19.20 | 19.20 |
| Pipelines | 6.00 | 5.36 | 4.54 | 3.86 |
| Platforms | 124.00 | 110.84 | 93.86 | 79.70 |
| Wells | 41.00 | 36.65 | 31.03 | 25.56 |
| MMV | 0.00 | 0.00 | 0.00 | 0.00 |
| Abandonment | 75.00 | 58.93 | 46.30 | 37.25 |
| Throughput $CO_2$ | 2 | 4 | 5 | 5 |
| Amortisation period | 20 | 25 | 30 | 35 |
| Annual OPEX% | 6.0% | 5.0% | 4.5% | 4.0% |
| PMT rate | 10% | 10% | 10% | 10% |
| IDC % | 15% | 15% | 15% | 15% |

| DOGF: High path coal | | 2013 | 2020 | 2028 | 2040 |
|---|---|---|---|---|---|
| Pre-FID | £m | 22.08 | 22.08 | 22.08 | 22.08 |
| Pipelines | £m | 6.90 | 6.70 | 6.36 | 5.99 |
| Platforms | £m | 142.60 | 138.36 | 131.54 | 123.81 |
| Wells | £m | 47.15 | 45.75 | 43.49 | 40.53 |
| MMV | £m | 0.00 | 0.00 | 0.00 | 0.00 |
| Abandonment | £m | 86.25 | 77.06 | 65.23 | 54.66 |
| Throughput $CO_2$ | mtpa | 2.00 | 3.00 | 4.00 | 4.00 |
| Amortisation period | years | 15 | 25 | 39 | 40 |
| Annual OPEX% | % | 6.0% | 5.0% | 4.5% | 4.5% |
| PMT rate | % | 10% | 10% | 10% | 10% |
| IDC % | % | 15% | 15% | 15% | 15% |

| DOGF: Low path gas | 2013 | 2020 | 2028 | 2040 |
|---|---|---|---|---|
| Pre-FID | 22.08 | 22.08 | 22.08 | 22.08 |
| Pipelines | 6.90 | 6.70 | 6.36 | 5.99 |
| Platforms | 142.60 | 138.36 | 131.54 | 123.81 |
| Wells | 47.15 | 45.75 | 43.49 | 40.53 |
| MMV | 0.00 | 0.00 | 0.00 | 0.00 |
| Abandonment | 86.25 | 77.06 | 65.23 | 54.66 |
| Throughput $CO_2$ | 2.00 | 3.00 | 4.00 | 4.00 |
| Amortisation period | 15 | 25 | 39 | 40 |
| Annual OPEX% | 6.0% | 5.0% | 4.5% | 4.5% |
| PMT rate | 10% | 10% | 10% | 10% |
| IDC % | 15% | 15% | 15% | 15% |

| DOGF: Adjusted coal | | 2013 | 2020 | 2028 | 2040 |
|---|---|---|---|---|---|
| Pre-FID | £m | 19.20 | 19.20 | 19.20 | |
| Pipelines | £m | 6.00 | 5.36 | 4.54 | |
| Platforms | £m | 124.00 | 110.84 | 93.86 | |
| Wells | £m | 41.00 | 36.65 | 31.03 | |
| MMV | £m | 0.00 | 0.00 | 0.00 | |
| Abandonment | £m | 75.00 | 58.93 | 46.30 | |
| Throughput $CO_2$ | mtpa | 2 | 4 | 5 | |
| Amortisation period | years | 15 | 25 | 25 | |
| Annual OPEX% | % | 6.0% | 5.0% | 4.5% | |
| PMT rate | % | 15% | 14% | 12% | |
| IDC % | % | 15% | 15% | 15% | |

| DOGF: Adjusted gas | 2013 | 2020 | 2028 | 2040 |
|---|---|---|---|---|
| Pre-FID | 19.20 | 19.20 | 19.20 | |
| Pipelines | 6.00 | 5.36 | 4.54 | |
| Platforms | 124.00 | 110.84 | 93.86 | |
| Wells | 41.00 | 36.65 | 31.03 | |
| MMV | 0.00 | 0.00 | 0.00 | |
| Abandonment | 75.00 | 58.93 | 46.30 | |
| Throughput $CO_2$ | 1 | 2 | 5 | |
| Amortisation period | 15 | 25 | 25 | |
| Annual OPEX% | 6.0% | 5.0% | 4.5% | |
| PMT rate | 15% | 14% | 13% | |
| IDC % | 15% | 15% | 15% | |

# Annex B – Cost reduction task force

## B.1 Task Force membership

- Alstom
- Air Liquide
- AMEC
- CCSA
- CCS TLM
- $CO_2$DeepStore
- Costain
- E.On
- Ecofin
- ETI
- Gassnova
- National Grid Carbon
- Norton Rose
- Progressive Energy
- SSE
- Scottish Government
- Scottish Enterprise/IPA
- SCCS
- Shell
- Societe Generale
- Statoil
- TCM
- The Crown Estate

**Additional Task Force contributions**

- Zurich
- Element Energy
- BGS
- 2CO
- BNP Paribas
- RBS
- Doosan Babcock

**Report sponsors**

- The Crown Estate
- CCSA
- DECC

## B. 2 Task Force terms of reference

The Carbon Capture and Storage (CCS) Cost Reduction Task Force is an industry-led joint task force established by Government to assist with the challenge of making CCS commercially available for operation by the early 2020s.

The Government is reforming the electricity market with the aim of providing a framework that will facilitate low carbon investment, including in CCS. The Government's objective is to have competition between low carbon generation technologies in the 2020s with the market deciding which of the competing technologies delivers the most cost-effective mix of supply and ensures a balanced electricity system. If CCS-equipped power stations are to play a significant role in the electricity market they will need to be cost-competitive with these other technologies.

In the industrial sector CCS provides one of the main opportunities for significant emissions reduction to mitigate the increasing cost of carbon. Cost reduction is essential to ensure that the UK industrial sector can be decarbonised at least cost and remains competitive.

The Government has launched a CCS Commercialisation Programme with £1bn in capital funding which aims to support practical experience in the design, construction and operation of commercial scale CCS. To avoid any conflicts of interest the Task Force will not advise the Government on development of that programme.

**Objective**

The objective of the Task Force is to publish a report to advise Government and industry on reducing the cost of CCS so that projects are financeable and competitive with other low carbon technologies in the early 2020s.

**Key activities**

The Task Force will:

A. identify and quantify the key cost components of CCS and the key cost reduction opportunities;

B. describe routes to realising these cost reductions and the actions required from industry and Government;

C. seek commitment from industry on initiatives to reduce cost and the steps Government could take to establish the right market framework and incentives to encourage industry to invest; and

D. Present to DECC Ministers:

   i. Interim findings, by Autumn 2012, setting out the opportunity and the planned programme of work; and

   ii. A final report, in early 2013, setting out findings and recommendations for action by Government and industry.


Image provided by Worley Parsons

All facts and figures are correct at time of print (May 2013).