



## UKERC ENERGY RESEARCH LANDSCAPE: CARBON CAPTURE AND STORAGE

[Section 1](#): An overview which includes a broad characterisation of research activity in the sector and the key research challenges

[Section 2](#): An assessment of UK capabilities in relation to wider international activities, in the context of market potential

[Section 3](#): Major funding streams and providers of *basic research* along with a brief commentary

[Section 4](#): Major funding streams and providers of *applied research* along with a brief commentary

[Section 5](#): Major funding streams for *demonstration activity* along with major projects and a brief commentary

[Section 6](#): Research infrastructure and other major research assets (e.g. databases, models)

[Section 7](#): Research networks, mainly in the UK, but also European networks not covered by the EU Framework Research and Technology Development (RTD) Programmes.

[Section 8](#): UK participation in energy-related EU Framework Research and Technology Development (RTD) Programmes

[Section 9](#): UK participation in wider international initiatives, including those supported by the International Energy Agency

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## 1. Overview

[Return to Top](#)

### Characterisation of the field

Most forecasts predict that fossil fuels will continue to play a major role in meeting global energy demand up to, and beyond, 2050, comprising as much as 50% of energy needs. As well as coal, oil and gas, this is likely to include increasing production from unconventional sources such as tar sands, coal-bed methane and coal-to-liquid. In this context, carbon capture and storage (CCS) is potentially a key global technology for mitigating emissions of CO<sub>2</sub> — the IPCC estimate that application of CCS worldwide could halve new CO<sub>2</sub> emissions (IPCC, 2005). In the 2006 IEA World Energy Outlook (Beyond Alternative Policy), CCS is a requirement to remove about 20% of CO<sub>2</sub> emissions, even if nuclear and renewables generation double. CCS deployment in the UK, at demonstration and early commercial stages, could provide working examples of technology, projects, regulatory and financial systems for other parts of the world, while also helping to meet national policy targets for UK CO<sub>2</sub> emission reductions. In addition to reduced emissions from power stations, CCS could also contribute to reducing transport sector emissions, via electric or hydrogen-powered vehicles.

Rather than a single technology, CCS spans a series of technologies which enable the capture of CO<sub>2</sub> from fossil fuels, transport of liquefied CO<sub>2</sub>, and its storage in the deep geological subsurface. There are a number of sub-fields or alternative pathways within this, including post-combustion capture, pre-combustion capture, oxyfuel capture, compression, transport, geological injection to aquifers, enhanced oil recovery, monitoring requirements to assure good site performance, and insurance requirements to enable developers to operate.

BERR are operating a competition within the UK, which will provide public funds to build the UK's first integrated coal combustion, capture, transport and storage system, to operate before end 2014.

Capture is the most expensive stage of the CCS chain, and substantial research efforts are being undertaken to reduce its energy penalty and associated costs. Of three possible capture methods, post combustion capture ('scrubbing') is the most mature, and is routinely used for flue gas separation in the petrochemicals industry or urea manufacture. The solvents need adaptation to resist the impure gases from power plants, and the equipment needs scaling-up by a factor of 10. This can be retrofitted, and is the option favoured within the UK BERR competition. Pre-combustion capture is technically elegant, and potentially a low-cost method of CO<sub>2</sub> separation integrated with fuel gasification and large scale hydrogen production on new plant. Pre-combustion separation is mature in petrochemical plants, although there is less experience of flowing process-integration with gasification. Oxyfuel capture is the least mature method, and is under development at large laboratory scale, for commercialisation by 2015. Oxyfuel burners could be retrofitted to enable concentrated CO<sub>2</sub> combustion gases to be efficiently separated. Cheaper separation of oxygen from air is required.

Transport of large quantities of CO<sub>2</sub> by pipeline is well established in the US (onshore). North Sea industries routinely use oil and gas pipes offshore, but only the Norwegian Snhovit field has an offshore CO<sub>2</sub> pipe since 1996, but a number of research challenges remain.

Geological injection offshore is proven only by the local Utsira experiment. Although enhanced oil recovery (EOR) with CO<sub>2</sub> is well established onshore in the US and elsewhere, several evaluations offshore have failed on cost. The injectivity rate and total volume of aquifers remains a significant unknown, as does the seal performance of mudrocks. Better evaluation methods are needed, with operational technology for CO<sub>2</sub> imaging and leak detection and cement remediation.

## Research Challenges

Key questions for the UK are the prediction and discovery of costs, the subsurface monitoring of injection and CO<sub>2</sub> position, prediction and detection of leakage for the time spans involved the ability to provide public acceptability.

- Development of the first full-scale electricity generation plant, with full-scale CO<sub>2</sub> capture as part of operation process will be expensive. Methods are needed to better understand the uncertainties of, and learning effects on, future cost developments. Are 50% capture savings feasible?
  - Improved efficiency of existing combustion technologies and the developing technologies needed to support the extra demands placed upon such equipment operating in increasingly aggressive environments.
  - CO<sub>2</sub> capture technologies able to handle large volumes of emissions, with improved efficiency and reduced capital and running cost. Post-combustion: resistant amine solvents or alternatives. Pre-combustion: improved membrane or pressure swing separation of both CO<sub>2</sub> and H<sub>2</sub>. Oxyfuel: cheaper O<sub>2</sub> separation from air, better membranes for CO<sub>2</sub> separation, chemical looping. Performance of capture during plant ramp-up and ramp-down in a flexible price market.
  - Transport: distances between CO<sub>2</sub> sources and sinks can be critical cost barriers to first entrants. Evaluation of pipeline re-use availability, staged entry opportunities, and optimisation of shared facilities are important for business relationships and financially. Purity of CO<sub>2</sub> affects compressor and pipeline design.
  - Determination of costs: Capex, e.g. of building new generation plants, retrofitting old plants, installing pipelines, infrastructure at storage sites. Opex offshore, including aquifers, depleted gas fields, Enhanced Oil Recovery platform costs, monitoring, verification protocols for all CCS. Also,
- Improving assessment of the availability of aquifer storage space. Such field assessment needs to be both in terms of volume and time.
  - Monitoring and verification technology needs to be adapted from existing hydrocarbon and mineral exploration or production, and trialled.
  - Improved basic techniques to evaluate CO<sub>2</sub> sealing vertically by mudrock and by faults
  - Enhanced Oil Recovery – how will geo-engineering methods be adapted for offshore use? Can gravity drive of CO<sub>2</sub> be used cheaply for improved production of total oil resource?
  - Investigation of natural CO<sub>2</sub> storage and leakage analogue sites as an aid to understanding and quantifying processes, and as an aid to communicating with the public. Environmental impacts of CO<sub>2</sub> leakage into shallow ocean bed and of onshore leakage in a UK setting.
  - Onshore legal and regulatory issues need to be addressed to investigate buffer stores for large projects, or low cost storage by smaller emitters. Clarification of national and supranational licensing, participation of CCS in emissions trading schemes, local, national and supranational environmental protection issues, ratification of international treaties such as OSPAR and the London Convention and its protocol.
  - Public acceptance is a potential showstopper. More investigation is needed to guide approaches to local communities affected. Public information and engagement is persistently neglected.

## 2. Capabilities Assessment

### [Return to Top](#)

The UK has no direct experience of carbon dioxide capture, but has a long experience of making boiler and turbine systems components for power stations with some UK companies and subsidiaries of trans-national companies. There is therefore a wide and deep experience base which is adapting improving combustion and power plant efficiency and to clean coal technologies. The Technology Ownership is not always strong in the UK, inventions and developments have been sold. There is a wide spectrum of innovative Original Equipment Manufacturers, at different component sizes. It is uncertain if the UK still retains all the capability to make a complete coal or gas plant domestically.

In simple terms, the UK is strong on supercritical coal and (potentially) ultrasupercritical coal plant. Gasifier technology is owned by US and oil companies - although opportunities exist by transfer of skills from UK chemical industry. Membranes and Air Separation could be developed

from a very strong university base of Materials and Chemical Engineering - there is a weak link to the established and dominant USA, French and German manufacturers - so that new Developments would need strong support to avoid being purchased.

The UK is very strong on subsurface evaluation and geo-engineering technologies because of the North Sea developments.

Likewise UK expertise in the whole supply chain of design, fabrication and installation of offshore equipment is uniquely strong. There are large companies and SMEs to fill many niches.

Financing, design and management of power and offshore projects are areas where the UK is perceived to be strong. The City of London is a major world centre for this. Carbon trading, relevant to EU-ETS, CDM and JIP, is undertaken through London markets.

**Table 2.1 Capability Assessment**

<b>UK Capability</b>	<b>Area</b>	<b>Market Potential</b>
<b>High</b>	<ul style="list-style-type: none"> <li>• Subsurface geological and engineering</li> <li>• Coal-fired supercritical boilers</li> <li>• Oxyfuel burners</li> <li>• Air separation units for oxyfuel</li> <li>• Turbines: gas and steam</li> <li>• Onshore pipes</li> <li>• Offshore pipes</li> <li>• Finance of projects</li> <li>• Carbon trading</li> <li>• Design of capture add-on</li> </ul>	<ul style="list-style-type: none"> <li>• World-leading offshore hydrocarbon techniques</li> <li>• Manufacturer within world top 5</li> <li>• Manufacturers research within world top 5</li> <li>• Excellent chemical engineering research, weak industry</li> <li>• Two /more world leading companies</li> <li>• Methane established technology</li> <li>• UK subsidiaries of global companies</li> <li>• City of London is a world centre + banks</li> <li>• World centre</li> <li>• Innovative companies and researchers</li> </ul>
<b>Medium</b>	<ul style="list-style-type: none"> <li>• Coal power station</li> <li>• Gas power station</li> <li>• CO<sub>2</sub> compression</li> <li>• Offshore EOR mechanical and geo-engineering</li>   <li>• Gasifiers of solid fuel</li> </ul>	<ul style="list-style-type: none"> <li>• International competition</li> <li>• International competition</li> <li>• One strong company</li> <li>• Will be needed to develop for EOR in UK, techniques could then be applied internationally</li> <li>• Research active, and industry heritage from chemical industry and national coal and power laboratories</li> </ul>
<b>Low</b>	<ul style="list-style-type: none"> <li>• Membranes for separation of CO<sub>2</sub>, O<sub>2</sub></li> <li>• Solvent CO<sub>2</sub> capture</li> <li>• CO<sub>2</sub> pipeline</li> <li>• Design of “capture ready” add-on</li> </ul>	<ul style="list-style-type: none"> <li>• Excellent materials research, Large specialist potential</li> <li>• Large market for new variants, no focus</li> <li>• Will be needed for EOR in UK</li> <li>• Will be needed in UK, China</li> </ul>

### 3. Basic strategic research

[Return to Top](#)

World-class research on CCS has been undertaken since the 1990's by the British Geological Survey, funded by the NERC, by a series of EU Programmes, and by industry. The BGS has tended to focus on transport and geological storage, and is very strongly involved in EU and worldwide networks. Existing staff are over-committed with the BERR competition, and increased capacity may be necessary.

BERR (formerly DTI) has funded a series of studies emerging from its coal technology and clean coal programmes – now in Energy sources/Sustainable technologies, operated by Technology Strategy Board. These are by a variety of contractors, often including AEA Energy and Environment (formerly FES), on all aspects of CCS – with extensive compilation of power plant data, evaluation or transport technical risks and markets. This has been less detailed on the geological aspects. Plymouth Marine Laboratory is the only (NERC-funded) institute to focus on ocean impacts of CCS at present, in the context of their basic work on shallow seas.

UK Universities have significantly coordinated CCS activity since 2004, enabled by the TSEC programme funded by NERC, EPSRC and ESRC; the UKCCSC coordinates that research activity of 14 Universities and institutes, and this is by far the largest virtual cluster of UK research activity. There is no training capacity specifically directed to CCS, but individual academics with UKCCSC have related PhD students. The Scottish Funding Council has enabled creation of a University Centre for CCS at Edinburgh and Heriot-Watt; this group has world-class expertise in subsurface geology and geophysics evaluation, geo-engineering and EOR, and forms the UK's largest physical cluster for that speciality. Nottingham has formed an institute for novel carbon capture technologies, partly by grouping existing staff and new recruitment. Edinburgh and Heriot-Watt are currently forming a new Centre of carbon Capture, by grouping existing staff and 12 new recruitments.

UKERC has experience of monitoring CCS developments, cross-compared to other energy technologies.

A large amount of 'capable' research is undertaken within conventional within science and engineering, but not badged as carbon capture or storage. This is especially within earth and environmental sciences, as well as general and chemical engineering. Management and business studies dominate among the humanities, with Tyndall (Manchester) and Bath hosting large research groups. Social science contributions are diffuse. There are also a small number of mathematicians and statisticians engaged in research in the area.

Data in 2006 was solicited by e-mail to individual academics within the UKCCSC. This has been up-dated in 2007 via a new round of e-mail solicitation. The coverage has been improved somewhat – not least with regard to capture-related research. This reflects a broader range of methods used for identifying researchers – mainly a news flow in national public and technical media, but also a search of EPSRC-funded projects, as well as information passed on through UKERC and UKCCSC networks during the year. Replies from 2006 have been retained in those cases where we received no 2007 reply (denoted with a \* in table 3.2).

The reliance on self-reported data tends to give an over-estimate of people involved in CCS research. This is due to the difficulty is assigning part-time effort, and to some duplication of reporting so that an individual may be double counted within, say, UKERC and University. A search of academic web-sites for CCS activity would yield much lower numbers of personnel involved, in many cases zero for individual institutions. This tends to give an under-estimate, due to the perennial problems of up-dating web information.

**Table 3.1: Basic Research Funding**

Funding stream	Funding Agency	Description	Committed Funds	Period	Representative Annual Spend
<a href="#">TSEC carbon management</a>	<a href="#">NERC/EPSRC/ESRC</a>	The <a href="#">UK Carbon Capture and Storage Consortium</a> (UKCCSC) is a consortium of engineering, technological, natural, environmental, social and economic scientists in 12 universities and 2 NERC Institutes. It undertakes integrated whole-system research. Sub-topics covered include CO <sub>2</sub> capture, transport and usage, geological storage, CCS & the environment, social processes, geographic information (GIS), dissemination, economic analysis, energy system modelling, dynamic pathways of change.	£2m	05 -08	£666k
<a href="#">Scottish Centre for Carbon Storage SCCS</a>	<a href="#">Scottish Funding Council, University of Edinburgh, Heriot-Watt University</a>	Start-up funds for key research staff, to become self-funding within 4 years. Focus on CO <sub>2</sub> storage, EOR, aquifer injection, leakage and monitoring. Industry-funded sponsor group	£2.6m	04 - 08	£650k
<a href="#">Scottish Centre for Carbon Capture</a>	EPSRC Scottish Funding Council Scottish Enterprise University of Edinburgh Heriot-Watt University	Creating capacity by grouping existing staff and recruiting new staff, to apply chemical engineering and process engineering to CO <sub>2</sub> capture at power plants. A strand of activity also investigates sequestration from air by pyrolysis of wood and crop, and soil re-fertilisation by biochar	£5M	08-13	£1M
<a href="#">Nottingham University</a>	EPSRC	Grouping existing staff on Energy and new recruitment to a Centre for Innovation in Carbon Capture and Storage CICCS	£1.1M	07-12	£210k
<a href="#">UK Energy Research Centre</a>	<a href="#">NERC/EPSRC/ESRC</a>	UKERC provides an integrated assessment and appraisal function, both vertically within different energy sectors, and crucially laterally to compare and relate between different sectors of current and future sustainable energy technologies. A strand on carbon management in Future Sources of Energy, and CCS Environmental Impacts within	£350k (of £12m)	04 -09	£70k

Funding stream	Funding Agency	Description	Committed Funds	Period	Representative Annual Spend
		Sustainability.			
Annual calls for proposal	<a href="#">BCURA</a>	BCURA (the British Coal utilisation research Association) funds, coal-related research, including a few efficiency or CCS-oriented projects.			
(Bi)-Annual call	TSB	Carbon Abatement Technologies are now operated by TSB, instead of BERR (DTI)	5M		£2M /yr in 2008
Responsive Mode	<a href="#">NERC</a>	University of Cambridge lead an academic consortium on fundamental geochemistry of CO <sub>2</sub> -rock interaction.	5M	08-13	1M

Table 3.2: Key Research Providers

Name	Description	Sub-topics covered	No of staff	Field
<a href="#">Centre for Sustainable Technologies</a> , <a href="#">School of the Built Environment</a> , <a href="#">University of Ulster</a>	The Centre for Sustainable Technologies (CST) is a multi-disciplinary research centre tackling many aspects of the diverse sustainability agenda. CST research can be broadly divided into three areas: renewable energy, clean combustion of fuels and energy efficiency in buildings and industry.	<ul style="list-style-type: none"> <li>• Simulation of capture and combustion</li> </ul>	4 staff and 2 PhD	Architecture and the Built Environment
<a href="#">Plymouth Marine Laboratory (PML)</a>	PML research is aimed at reducing uncertainty about the processes that take place within the marine environment. Developing an understanding of ecological processes helps to quantify risks and minimise them through effective management.	<ul style="list-style-type: none"> <li>• Ocean ecology</li> <li>• Ocean currents</li> <li>• Effects of atmospheric and marine CO<sub>2</sub> on ecosystems</li> <li>• Environmental chemistry</li> <li>• QSAR-based modelling</li> <li>• Biomarker development and validation</li> <li>• Remote/satellite surveillance</li> <li>• Interpretation of complex information</li> </ul>	5 full time research staff, 9 total	Biological Sciences



Name	Description	Sub-topics covered	No of staff	Field
<a href="#">School of Biosciences,</a> <a href="#">University of Nottingham</a>	Internationally recognised for an outstanding quality of teaching and research, the School of Biosciences is divided into 5 academic divisions: - Agricultural & Environmental Sciences, Animal Physiology, Nutritional Sciences, Plant Sciences, Food Sciences.	<ul style="list-style-type: none"> <li>• Simulation, modelling</li> <li>• Detection of soil CO<sub>2</sub></li> <li>• Effects of enhanced CO<sub>2</sub> on biota</li> <li>• Dispersion of CO<sub>2</sub> release</li> </ul>	5 people	Biological Sciences
* <a href="#">School of Construction Management and Engineering,</a> <a href="#">University of Reading</a>	The School's research has a world-wide reputation for quality and innovation and has been influential in developing and improving the processes and techniques of the construction and development industry. Research priorities reflect the constantly changing needs of the construction and engineering sector.	<ul style="list-style-type: none"> <li>• Fossil fuel lifecycle cost modelling</li> <li>• Fossil fuel emissions</li> <li>• Integrated multi-disciplinary optimization of energy systems</li> <li>• Socio-Techno-Economic Modelling</li> </ul>	1 staff, 1 PostDoc, 2 MSc	Built Environment
<a href="#">Policy Research in Engineering, Science and Technology (PREST)</a> <a href="#">Manchester Business School,</a> <a href="#">University of Manchester</a>	PREST undertakes research and advisory work, and provides research training in the fields of science and technology policy and management studies through postgraduate degrees and topic-orientated short courses.  These staff are also part of Tyndall (North)	<ul style="list-style-type: none"> <li>• Stakeholder perceptions</li> <li>• Public perceptions</li> <li>• Policy analysis of CCS from socio-political and institutional perspectives</li> <li>• Energy scenarios and their assessment</li> <li>• Sustainability appraisal</li> </ul>	2 staff, 3 Post Docs	Business and Management Studies
* <a href="#">Judge Business School,</a> <a href="#">University of Cambridge</a>	Research at the Judge Business School aims to identify ways to improve business performance, to develop theory and methodology and to inform policy and practice in the public and private sector. Research centres include: the Centre for Corporate Governance, the Centre for Financial Research, the Centre for International Business and Management and Cambridge University Health.	<ul style="list-style-type: none"> <li>• Public acceptability</li> <li>• Stakeholder analysis</li> <li>• Integrated assessment</li> <li>• Policy evolution</li> <li>• International environmental negotiations</li> </ul>	1 staff, 1 RA, 1 PhD	Business and Management Studies

Name	Description	Sub-topics covered	No of staff	Field
<a href="#">Engineering Doctorate Training Centre - Efficient Power from Fossil Energy and Carbon Capture Technologies</a> , the University of Nottingham	This EngD Centre will produce research leaders to tackle the major national and international challenges over the next 15 years in implementing new power plant to generate electricity more efficiently using fossil energy with near zero emissions, involving the successful demonstration of CO <sub>2</sub> capture, and reducing CO <sub>2</sub> emissions generally from coal utilisation, including iron making.	<ul style="list-style-type: none"> <li></li> </ul>		Engineering
<a href="#">Sussex Energy Group / SPRU - Science and Technology Policy Research</a> ,  <a href="#">University of Sussex</a>	The Sussex Energy Group is one of the largest groups of social scientists conducting research on climate change and energy issues in the UK. It is core funded by the ESRC under the Research Councils' Towards a Sustainable Energy Economy (TSEC) programme. Through SEG, the University of Sussex is a partner in the Tyndall Centre for Climate Change Research. The main objective of the Group is to respond to challenges set out in the UK Energy White Paper of 2003 that require profound changes in our energy system. The Group takes an inter-disciplinary, systems perspective, recognising the scale and complexity of the challenge and the pervasiveness of uncertainties.	<ul style="list-style-type: none"> <li>CCS economics and incentives for innovation and deployment</li> <li>Corporate capabilities in CCS technologies</li> </ul>	4 staff	Business and Management Studies / Politics and International Studies
* <a href="#">Department of Chemical Engineering and Chemical Technology</a> ,  <a href="#">Imperial College</a>	Research is organised into eleven multidisciplinary focus areas which cover most aspects of chemical engineering and related scientific disciplines.	<ul style="list-style-type: none"> <li>CCS in coal seams</li> <li>Phase equilibria of fluids</li> </ul>	4 staff, 4 PhD	Chemical Engineering
<a href="#">School of Chemical Engineering and Advanced</a>	The School received a 5-rating in RAE2001. The School's research mission is to deliver	<ul style="list-style-type: none"> <li>CO<sub>2</sub> separation from combustion processes using</li> </ul>	9 staff, 4 Post Docs, 10 PhD.	Chemical Engineering

Name	Description	Sub-topics covered	No of staff	Field
<a href="#">Materials,</a> <a href="#">Newcastle University</a>	leading-edge research to address the major societal challenges we face in the areas of clean water, low-carbon energy, bioprocessing and sustainability while performing fundamental chemical engineering research to underpin this activity.	ceramic membranes.	These numbers include non-CCS research.	
<a href="#">Chemical Engineering,</a> <a href="#">University of Cambridge</a>	Research interests in the Department of Chemical Engineering cover a broad range of topics concerned with Chemical, Biochemical and Process Engineering. The academic staff are active in one or more of four research themes: Modelling, Measurement, Microstructure Engineering, Processes	<ul style="list-style-type: none"> <li>• Fluidised reaction systems for clean coal plants</li> <li>• CO<sub>2</sub> separation</li> </ul>	3 staff	Chemical Engineering
<a href="#">Institute for Materials and Processes,</a> <a href="#">University of Edinburgh</a>	The Institute for Materials and Processes joins researchers from materials science, materials synthesis and processing, and manufacturing optimisation. The objectives of the institute are to carry out world-class research on the design, synthesis, processing, properties and applications of materials, to develop relevant research tools, and to provide high quality training in research for both postgraduate students and postdoctoral researchers. These staff are part of the Scottish Centre for Carbon Storage	<ul style="list-style-type: none"> <li>• CO<sub>2</sub> separation</li> </ul>	3 staff 3 Post Docs 6 PhD	Chemical Engineering  Metallurgy and Materials
* <a href="#">Department of Earth Sciences,</a> <a href="#">University of Bristol</a>	Research is focused on five groups, with an emphasis on interdisciplinary collaboration between them: Deep Earth, Isotope Geochemistry, Volcanology, Sedimentology and Fluid Flows, Earth System Science and Aqueous, Geochemistry, Palaeobiology and	<ul style="list-style-type: none"> <li>• Passive seismic monitoring</li> <li>• Predicting 4d seismic properties</li> <li>• Linked seismic and geomechanical modelling</li> </ul>	2 staff, 1 Post Doc, 1 PG	Earth Sciences  Environmental Sciences

Name	Description	Sub-topics covered	No of staff	Field
	Biodiversity			
* <a href="#">Department of Earth Sciences</a> <a href="#">University of Cambridge</a>	Research areas include Geophysics & Tectonics, Basin and Crustal Development, Sedimentology, Igneous and Metamorphic Studies, Mineralogy and Mineral Physics, Palaeobiology and Palaeoecology, Environmental Change and Marine Geochemistry.	<ul style="list-style-type: none"> <li>• Modelling and imaging CO<sub>2</sub> flows at Sleipner</li> <li>• Thermodynamics, kinetics and geochemical signatures of reaction processes in reservoirs</li> <li>• Geochemical/isotopic monitoring of reactions</li> </ul>	3 staff 1 Post Doc 1 PhD	Earth Sciences  Environmental Sciences
* <a href="#">School of Geosciences</a> , <a href="#">University of Edinburgh</a>	The School is a leading international centre for research into GeoSciences. An industry sponsored group exists  These staff are part of the Scottish Centre for Carbon Storage	<ul style="list-style-type: none"> <li>• Reactions of CO<sub>2</sub> in reservoirs</li> <li>• Natural analogues to CCS</li> <li>• CO<sub>2</sub> leakage rates</li> <li>• Monitoring of CO<sub>2</sub></li> <li>• Detection of dissolved CO<sub>2</sub></li> <li>• Whole system CCS</li> <li>• CPD courses CCS</li> </ul>	5 staff, 7 Post Doc, 6 PhD	Earth Sciences  Environmental Sciences
<a href="#">Earth Surface Dynamics Research Group</a> , <a href="#">Department of Geographical and Earth Sciences</a> <a href="#">University of Glasgow</a>	This interdisciplinary research group aims to develop an integrated understanding of the evolution of the Earth's surface and near-surface environments	<ul style="list-style-type: none"> <li>• Subsurface CO<sub>2</sub> flow</li> <li>• Effects of faults</li> <li>• CO<sub>2</sub> leakage effects</li> </ul>	1 staff, 1 PhD	Earth Sciences  Environmental Sciences
<a href="#">Department of Earth Science and Engineering</a> , <a href="#">Imperial College</a>	Engineering solutions are used to provide the technology to solve problems in fundamental science, and fundamental science is used to provide the insight to solve applied problems of practical engineering.	<ul style="list-style-type: none"> <li>• CO<sub>2</sub> storage in hydrocarbon reservoirs and aquifers</li> <li>• CO<sub>2</sub> multiphase flow properties</li> <li>• CO<sub>2</sub> in coal beds</li> <li>• CO<sub>2</sub> storage security</li> </ul>	3 staff, c. 7 RA/PhD not directly engaged on CCS	Earth Sciences  Environmental Sciences
* <a href="#">School of Earth and Environment</a> and the <a href="#">Rock Deformation Research Group</a> ,	Research interests span studies of the Earth, the hydrosphere and the atmosphere, and issues of environmental management and sustainability. Research is grouped into four Institutes (Atmospheric Science,	<ul style="list-style-type: none"> <li>• Sub-surface flow of fluids</li> <li>• Multi-phase flow in rocks</li> <li>• Mineral cementation</li> <li>• Fracturing and fluid flow</li> <li>• Faults and seal</li> </ul>	2 staff, 1 Post Doc 1 MSc, 1 PhD	Earth Sciences  Environmental Sciences

Name	Description	Sub-topics covered	No of staff	Field
<a href="#">University of Leeds</a>	Geological Sciences, Geophysics and Tectonics and Sustainability Research). The Rock Deformation Research Group is an established market leader in structural geology, research and consultancy. Based in Leeds UK, RDR offers a wide range of services to hydrocarbon and mineral industries worldwide.	<ul style="list-style-type: none"> <li>• Geochemical reaction kinetics</li> <li>• Ion exchange capacity of reservoir rocks</li> </ul>		
<a href="#">School of Civil Engineering and Geoscience</a> and <a href="#">School of Marine Science and Technology</a> ,  <a href="#">University of Newcastle</a>	The traditional research strengths of the School of Civil Engineering and Geosciences (CEG) lie in the fields of Civil Engineering, Transport, Geomatics, Environmental Engineering, Water Resources, Soils, Biogeochemistry and Energy Resources. Marine Technology at Newcastle leads research into design, offshore engineering, marine engineering, computational fluid dynamics, high-performance computing, hydrodynamics and decision support work.	<ul style="list-style-type: none"> <li>• Geological seal integrity</li> <li>• Pipeline engineering (offshore/onshore)</li> <li>• Hydraulic and risk analysis</li> <li>• Phase modelling</li> <li>• GIS technology : routing studies</li> <li>• Ship design</li> <li>• Offshore engineering</li> </ul>	4 Staff 2 Post Docs	Earth Sciences  Environmental Sciences  Civil Engineering
<a href="#">British Geological Survey (BGS)</a>	BGS's Sustainable and Renewable Energy Programme researches carbon dioxide capture and geological storage, geothermal energy, underground storage of natural gas and hydrogen, UK onshore energy resources, new exploitation technologies for coal and UK subsurface reservoirs and UK subsurface geology in general. BGS has a strong track record in CCS-related research stretching back to 1991. BGS has contributed to many of the EU Framework programme projects on CCS and supplied Lead Authors to the IPCC Special Report on CCS and the CCS section of the revised IPCC guidelines for compiling	<ul style="list-style-type: none"> <li>• CCS monitoring and verification</li> <li>• UK and generic CO<sub>2</sub> storage capacity research</li> <li>• Geochemical experimentation into CO<sub>2</sub> water/rock reactions under subsurface conditions</li> <li>• CO<sub>2</sub> clathrates</li> </ul>	At any one time, up to 16 research and technical staff may be working on CCS.  Core group of 5 staff at Keyworth  5 staff part-time at Edinburgh	Earth Sciences

Name	Description	Sub-topics covered	No of staff	Field
	greenhouse gas inventories. It has also contributed to the OSPAR Framework for Risk Assessment and Management and the London Convention Waste Assessment Guideline for CO <sub>2</sub> storage in sub-sea geological formations. Part of BGS Keyworth is contracted to BERR 2008-09 to review CCS competition technical issues and bids.			
<a href="#">Scottish Centre for Carbon Storage</a>	<p>This grouping is funded by the Scottish Higher Education Funding Council to apply and extend established world-class expertise based on petroleum and hydrocarbon geoscience in: geology, geophysics, geo-engineering and subsurface fluid flow. A particular feature is the long-established research collaboration relationships with oil companies worldwide. This has now been extended to form a University to CCS industry consortium</p> <p>These staff are at University of Edinburgh Heriot Watt University BGS (Edinburgh)</p>	<ul style="list-style-type: none"> <li>• Experimental PVT studies of CO<sub>2</sub> with varying hydrocarbons</li> <li>• Hydrates and clathrates in porous media and pipes</li> <li>• Seismic processing and interpretation</li> <li>• Novel seismic survey acquisition and processing</li> <li>• Micro-seismicity in real-time to determine fluid migration</li> <li>• Rock physics experiments of mudrock seal deformation and re-seal</li> <li>• Petrographic investigation of CO<sub>2</sub>-brine and rock interaction</li> <li>• Fluid migration tracing by natural isotopes and artificial tracers</li> <li>• Geochemical interaction simulation of CO<sub>2</sub> -brine-hydrocarbon</li> <li>• Fluid migration modelling through overburden and in aquifers</li> <li>• Natural analogue studies to</li> </ul>	21 academic staff 7 Post Docs 15 PhD 6 MSc	<p>Earth Sciences</p> <p>Environmental Sciences</p> <p>Chemistry</p> <p>Physics Applied Mathematics</p> <p>Statistics and Operational Research</p> <p>General Engineering</p> <p>Education</p>

Name	Description	Sub-topics covered	No of staff	Field
		determine durability and processes <ul style="list-style-type: none"> <li>• Mudrock seal petrology, and permeability modelling</li> <li>• Integration with UK energy research networks: renewables, fossil, nuclear</li> <li>• Regional assessment of aquifers, structures and seals</li> </ul>		
* <a href="#">Business School, University of Aberdeen</a>	University of Aberdeen Business School (UABS) was formed by a merger of the departments of Accountancy-Finance, Economics, Property and Management. Within the Business School, the Department of Economics at Aberdeen has a well-established tradition of research in applied economics, particularly in the areas of Labour Economics and Natural Resource Economics.	<ul style="list-style-type: none"> <li>• Social processes and CCS</li> </ul>	2 staff, 1 Post Doc	Economics and Econometrics
* <a href="#">Department of Electrical and Electronic Engineering, Imperial College</a>	Research activities within the Department are organised broadly into five groups: Circuits & Systems, Communications & Signal Processing, Control & Power, Intelligent Systems & Networks and Optical & Semiconductor Devices	<ul style="list-style-type: none"> <li>• National Grid simulation</li> </ul>	1 staff, 1 RA	Electrical and Electronic Engineering
* <a href="#">School of Applied Sciences, Cranfield University</a>	Key areas of research relate to materials, manufacturing, natural resources and sustainable systems.	<ul style="list-style-type: none"> <li>• Gas cleaning</li> <li>• Fuel-related processes</li> </ul>	3 total	General Engineering
<a href="#">Institute of Petroleum Engineering, Heriot-Watt University</a>	The Institute is multi-disciplinary and focuses on upstream oil and gas resources. It was founded in 1975 to work with the emerging upstream North Sea industry and now has well established industrial and	<ul style="list-style-type: none"> <li>• Geophysics</li> <li>• Reservoir characterisation</li> <li>• Flow in porous media</li> <li>• PVT and reservoir fluids, Tracers</li> </ul>	11 staff, 6 PhD	General Engineering

Name	Description	Sub-topics covered	No of staff	Field
	academic links around the world. Most of the research projects are supported by several industrial partners, sometimes in collaboration with public sector funding.  These staff are listed as Scottish Centre for Carbon Storage	<ul style="list-style-type: none"> <li>• Gas hydrates</li> <li>• Hydrocarbon recovery processes, EOR, EGR</li> <li>• Geo and rock mechanics</li> <li>• Reservoir chemistry and production</li> <li>• CO<sub>2</sub> Storage</li> </ul>		
<a href="#">School of Chemical Engineering, Heriot-Watt University</a>	Research focused on principles of novel carbon capture or CO <sub>2</sub> separation	<ul style="list-style-type: none"> <li>• Ionic solvents</li> <li>• Membranes</li> <li>• Gas-liquid separation</li> </ul>	4 staff 2 PhD	General engineering
* <a href="#">School of Chemical, Environmental and Mining Engineering, University of Nottingham</a>	SChEME is home to novel research in the areas of microwave processing to extract rare and valuable minerals, green chemistry, clean and green water, nanotechnology, magnetic levitation and carbon dioxide capture to reduce the risk of global warming.	<ul style="list-style-type: none"> <li>• CO<sub>2</sub> capture</li> <li>• Low temperature absorption</li> <li>• Membranes</li> <li>• Oxy-fuel firing</li> </ul>	Total (not all CCS): 6 staff, 8 Post Docs, >12 PG	General Engineering
<a href="#">CICCS – Centre for Innovation in Carbon Capture and Storage, University of Nottingham</a>	The Centre for Innovation in Carbon Capture and Storage (CICCS) works on research at the interface of science and engineering, and international cooperation in order to accelerate technological innovation in the field and lead to a wider deployment of carbon capture and storage. The Centre will also have a strong programme on knowledge transfer and training with a range of opportunities for industrial engagement.	<ul style="list-style-type: none"> <li>• Cleaner coal</li> <li>• CO<sub>2</sub> capture</li> <li>• Light harvesting</li> <li>• Mineral carbonation</li> <li>• Storage</li> <li>• Monitoring</li> <li>• Public acceptability, regulatory issues and economy</li> </ul>	16 staff (not all full time)	General Engineering  Mathematics  Bioscience  Geography  Earth Science
<a href="#">School of Engineering, Energy Technology Centre Cranfield University</a>	Research in the School of Engineering is focused on four research themes centered on and facing nationally important industrial sectors: aerospace engineering and air transport, computational science and engineering, engineering photonics,	<ul style="list-style-type: none"> <li>• Modelling of combustion and heat transfer</li> <li>• CO<sub>2</sub> separation</li> </ul>	1 staff ?? PDRA ?? PhD ?? MSc	General engineering ??



Name	Description	Sub-topics covered	No of staff	Field
<a href="#">Energy and Resources Research Institute,</a>  <a href="#">Leeds University</a>	structures and machine systems.  The Vision is " <i>To be recognised for internationally leading research in the sustainable development of natural resources, the sustainable use of fossil fuels and the development of renewable and future fuels.</i> "  ERRI is involved in many forefront areas of energy and resource research, with an activity spectrum ranging from environmental and pollution monitoring to developing biomass resources and processes.	<ul style="list-style-type: none"> <li>• Modelling of Pulverised Coal Combustion</li> </ul>	3 staff 2 PhD ??	General engineering ??
* <a href="#">School of Geography,</a>  <a href="#">University of Nottingham</a>	The School's research community is organised into five Research themes: Cultural and historical geography, environmental management and policy, geographical information science, new economic geographies, environmental and geomorphological sciences.	<ul style="list-style-type: none"> <li>• Effects of CO<sub>2</sub> leakage on flora</li> <li>• Climate change</li> </ul>	2 staff	Geography  Environmental Sciences
<a href="#">Centre for Law and the Environment,</a>  <a href="#">University College London</a>	The main goals of the Centre are to advance research and teaching and explore the role of law in meeting contemporary environmental challenges. The Centre is committed to treating domestic law (UK), regional (European Union) and international aspects of environmental law in a comprehensive and integrated manner.	<ul style="list-style-type: none"> <li>• Analysis of the key legal questions arising from CCS activities</li> </ul>	3 staff	Law
* <a href="#">Department of Mechanical Engineering,</a>  <a href="#">Imperial College</a>	Research activities stem from a strong base of fundamental engineering research that provides the foundation for practical applications in energy, transport, defence and health care sectors.	<ul style="list-style-type: none"> <li>• Power plant design</li> <li>• Supercritical coal plant</li> <li>• Oxyfuel combustion</li> <li>• Biomass co-combustion</li> <li>• Carbon capture, retrofitting</li> <li>• Novel capture technologies</li> </ul>	4 staff 2 RA 4 PhD	Mechanical, Aeronautical and Manufacturing Engineering

Name	Description	Sub-topics covered	No of staff	Field
* <a href="#">Robert Gordon University</a>	RGU in Aberdeen is focused on work relevant to the offshore and energy industries.	<ul style="list-style-type: none"> <li>• Membrane separation of CO<sub>2</sub> flue gas</li> <li>• Acid Gas Removal from Natural Gas Streams</li> <li>• Hydrogen Production</li> <li>• Dehydration of hydrogen</li> <li>• Membrane Reactor Research</li> <li>• Synthesis Gas Operation</li> </ul>	3 staff 2 PDRA 1 PhD	Mechanical, Aeronautical and Manufacturing Engineering
<a href="#">Department of Materials, Imperial College</a>	The department has research interests ranging from metals, biomaterials and tissue engineering, nanotechnology and ceramics, particularly SOFCs and related technologies.	<ul style="list-style-type: none"> <li>• Ceramic oxygen separation membranes for CCS</li> <li>• Partial oxidation membranes for Pre-Combustion De-Carbonisation</li> <li>• Ash and coal properties in oxyfuel combustion</li> </ul>	2 Staff, 1 PG, some UG project students	Metallurgy and Materials

#### 4. Applied research

[Return to Top](#)

Applied research is provided by a range of consultancy companies and organisations with expertise in the sectors of technology appraisal, environment, or geoscience. Major trans-national companies have some very significant research and technology teams, some of this could be considered as being based in the UK and these will sometimes participate in, or be co-funded by, publicly-funded projects, especially from DTI/BERR/TSB.

BERR and the IEA GHG programme have also been key strategic funders. Substantial activity is occurring in other countries' national laboratories and research organisations. Regional development agencies, Scottish Enterprise, and ITI Scotland have funded evaluations which are perceived to have potential value for their position, but have no known long-term strategy for CCS. NGOs, the Carbon Trust, the Sustainable Development Commission etc, have frequently mentioned CCS as one of many low carbon options but there is no focused campaign to evaluate and provide new information.

Energy Technology Institute plans to identify CCS as one of 5 focus areas from 2008.

Company responses cover the 'core' CCS industries of electricity generators and oil and gas. Manufacturing companies are included in the role of suppliers to the core industries. Related service industries include legal firms, and consultants – mainly in engineering.

Potential research providers were identified from membership of the CCS trade association in early May 2006 (CCSA), and from attendance at CCS-related meetings, and contacted by email. In those cases where we have not received new replies in 2007, last year's data is marked with an \*.

Our coverage may be low. Compare approximately 10 identified providers of applied research with the approximately 50 members of CCSA. However, it is true that not all CCSA members do conduct any applied research. Some companies who do undertake research into CCS may also have chosen not to supply information for commercial reasons. The data relating to EU projects in section 8 suggest that more companies are involved in research than those listed here.

IEA GHG is excluded, as this is not UK-national, although it is based in the UK. IEA GHG is also covered in section 9.

**Table 4.1: Applied Research Funding**

Programme	Funding Agency	Description	Committed Funds	Period	Representative Annual Spend
<a href="#">DTI Clean Coal and Carbon Abatement Technologies (CAT strategy)</a>	TSB (formerly <a href="#">BERR</a> )	Arms length body, responsible to DIUS (2008) Formerly BERR and then DTI fossil fuels. Focused on efficiency improvements and carbon-free power from fossil fuel. This includes Enhanced Oil Recovery, which does not seem to be tackled by DTI Oil and Gas	£35m	07-11	£7m
<a href="#">Energy Sources Cleaner fossil fuels technology</a>	<a href="#">BERR</a>	This is operated under the remit of the CAT Programme (Carbon Abatement Technology). Cleaner Fossil Fuels Technology covers a range of technologies which deal with the emissions generated by fossil fuel power generation. The emphasis is currently on reducing emissions from coal-fired power generation			
<a href="#">Greenhouse Gas R&amp;D Programme (IEA GHG)</a>	<a href="#">IEA</a>	The IEA Greenhouse Gas R&D Programme (IEA GHG) is an Implementing Agreement of the International Energy Agency, and was founded in 1991. It is a major international research collaboration that assesses technologies capable of achieving deep reductions in greenhouse gas emissions. CCS is a major component of the programme.			
Ad-hoc	NGO CCSA C Trust Sust Dev Comm. See text above	No coherent data Work has been undertaken by Green Alliance, Friends of the Earth, Greenpeace. None known to be focused on CCS, but rather CCS placed in context of Energy policy or CO <sub>2</sub> reduction			

**Table 4.2: Key Research Providers**

Name	Description	Sub-topics covered	Scale of operation	Sector
* <a href="#">Air Products</a>	Manufacturer of atmospheric gases, process and specialty gases, performance materials and chemical intermediates. The company has built leading positions in key growth markets, such as semiconductor materials, refinery hydrogen, home healthcare services, natural gas liquefaction, and advanced coatings and adhesives. Also potentially relevant for Oxyfuel firing. HQ in USA	<ul style="list-style-type: none"> <li>• Cryogenics</li> <li>• Materials</li> </ul>	UK CCS budget 3m USD	Manufacturing
<a href="#">British Geological Survey</a>	Responsible for advising the UK government on all aspects of geoscience as well as providing impartial geological advice to industry, academia and the public.	<ul style="list-style-type: none"> <li>• Geology</li> <li>• Infrastructure</li> <li>• Carbon capture and storage</li> <li>• International policy advice</li> <li>• Reservoir Characterisation, Storage &amp; Production</li> <li>• Regional Subsurface Structure</li> <li>• Gas Storage</li> <li>• Onshore Hydrocarbon &amp; Coal Resources</li> </ul>	16 staff (research and technical), 1 PhD. Also 4 staff for hydrates 7 for non-CCS CO <sub>2</sub> .	R&D science and engineering  Other non-departmental public body
<a href="#">Doosan Babcock Energy</a>	Provide a range of services in support of power generation. Range of specialist products and services to clients across the thermal power, petrochemical and process, nuclear, pharmaceutical, oil and gas and industrial markets. Global	<ul style="list-style-type: none"> <li>• Capture-ready supercritical coal-fired boilers</li> <li>• Oxy-fuel firing of coal CCS</li> <li>• Amine scrubbing</li> <li>• Integration of CC into power plant design, retrofits</li> </ul>	10+ personnel  Budget £2m p.a.  Whole Technology Centre 250 staff	R&D science and engineering  Manufacturing  Consulting engineers

Name	Description	Sub-topics covered	Scale of operation	Sector
	company with offices and locations across all the major energy markets. Major coal boiler R&D and manufacturing facility at Renfrew UK.			
<a href="#">Environmental Resources Management Ltd</a>	Environmental Resources Management (ERM) is one of the world's leading providers of environmental consulting services. ERM has over 100 offices in 40 countries and employ over 3,000 staff. ERM is committed to providing a service that is consistent, professional and of the highest quality. Delivery of innovative solutions for leading business and government clients, assisting them in managing their environmental and related risks. ERM describe themselves as an environmental consultancy, and from their reply clearly cover a broader area than just management consulting.	<ul style="list-style-type: none"> <li>• Policies, laws, regulations and incentives.</li> </ul>	20 - 30 people with CCS expertise	Management Consulting
<a href="#">E.ON Energy</a>	E.ON UK is the UK's largest integrated power and gas company, generating and distributing electricity and supplying power and gas to domestic and business customers nationwide. Part of the E.ON group, the world's largest investor-owned energy	<ul style="list-style-type: none"> <li>• Capture</li> <li>• Storage</li> <li>• Transportation</li> <li>• Utilisation areas</li> </ul>	<p>Around £550k not including project development activities</p> <p>Approximately 6 full time people (Around 12 part time people)</p>	Electricity and gas

Name	Description	Sub-topics covered	Scale of operation	Sector
	services provider, with ambition to becoming the world's leading power and gas company.			
* <a href="#">Hammonds</a>	Hammonds is a leading commercial law firm with offices throughout the UK, Europe and in Asia	Regulatory regime: <ul style="list-style-type: none"> <li>• Long-term liability</li> <li>• Monitoring</li> <li>• Carbon crediting</li> <li>• Regulatory incentives/ obstacles</li> <li>• Pipeline regulations</li> </ul>	c.12 (not full time)	Legal activities
<a href="#">Herbert Smith</a>	Leading and full-service international legal practice with a 1,100-lawyer network across Europe, Asia and the Middle East. UK firm of the year 2006 (International Law Office Client Choice Awards). The global energy team has consistently been recognised as a top-tier practice by leading legal directories for the last seven years. Have advised on the leading UK deals to date (including Centrica/Progressive, BP/Rio Tinto investments in CCS in UK, US and Australia). Hammonds are contributors to CCSA, London Accord and other CCS and aligned organisations on the legal aspects of their research.	<ul style="list-style-type: none"> <li>• Treatment of CCS under the EU ETS</li> <li>• Interface with environmental legislation</li> <li>• International law requirements and incentives (eg. marine and climate change conventions)</li> <li>• Offshore decommissioning obligations</li> <li>• Planning issues</li> <li>• On and offshore pipeline regulation</li> <li>• Project development including: corporate structures, fuel supply and off-take arrangements, feed arrangements and financing</li> <li>• Development and regulation of power plants</li> <li>• Gas storage</li> </ul>	6-8 lawyers currently engaged on CCS related matters.	Legal activities
<a href="#">ILF Consulting Engineers Ltd</a>	ILF is an international design consultant specialising in the transportation and storage of all hydrocarbons and water. This	<ul style="list-style-type: none"> <li>• Pipelines</li> <li>• Optimisation along the supply chain</li> <li>• Underground gas storage.</li> </ul>	€ 100 000	Consulting Engineers  Management Consulting

Name	Description	Sub-topics covered	Scale of operation	Sector
	includes pipelines, terminals, underground and above ground storage and safety monitoring systems. ILF has designed over 2000 pipelines around the world which includes the transportation of high CO <sub>2</sub> content gases and gases in the supercritical phase. ILF also has some design and operational experience of gas storage in on-shore aquifers.			
* <a href="#">Norton Rose</a>	International lawyers specialising in corporate finance, financial institutions, energy and utilities, technology and transport.	<ul style="list-style-type: none"> <li>• Legal aspects of CCS</li> </ul>	5 lawyers	Legal activities
* <a href="#">Schlumberger</a> Carbon Services	A leading oilfield services provider, delivering superior results and improved E&P performance for oil and gas companies around the world. Schlumberger Carbon Services are in Abingdon. This is part of a much larger carbon services group worldwide, headquartered in Paris	<ul style="list-style-type: none"> <li>• All CO<sub>2</sub> engineering services</li> <li>• Reservoir modelling of CO<sub>2</sub> storage fields</li> <li>• Wireline detection of CO<sub>2</sub></li> <li>• Monitoring technologies</li> <li>• Cement technologies</li> </ul>	2	Energy extraction
* <a href="#">Scottish &amp; Southern</a>	Scottish and Southern Energy is one of the largest energy companies in the UK, involved in the generation, transmission, distribution and supply of electricity; energy trading; the storage, distribution and supply	<ul style="list-style-type: none"> <li>• Gas fired CCS plants</li> <li>• Coal fired CCS plants</li> <li>• Integrated gasification</li> <li>• Coal-bed methane</li> <li>• Legal, environment</li> <li>• Health &amp; Safety</li> </ul>	c. 10 people	Electricity and gas



Name	Description	Sub-topics covered	Scale of operation	Sector
	of gas; electrical and utility contracting; and telecoms. HQ Perth, Scotland.			
<a href="#">RWE</a>	Npower is part of the German RWE group	<ul style="list-style-type: none"><li>• Experimental slipstream capture of CO<sub>2</sub></li></ul>	?2	Electricity and gas

## 5. Development and Demonstration Funding

[Return to Top](#)

Demonstration funding has been allocated by the BERR, as part of its CAT strategy. This was initially £25m, and was then increased by the Chancellor to £35m in a pre-budget statement 2005. This is small compared to 1) the £100m minimum requested by the BERR advisory board, and 2) the cost of a gas or IGCC power station of £400-1,500m, and 3) the USA FutureGen initiative of \$1,500m. As part of the BERR CCS competition, Government has indicated that it intends to pay for the costs of adding capture (whilst the technology is developed), but not the whole cost of the plants. BERR will also underwrite the price difference of Demonstration CCS electricity and the EU-ETS price. This is estimated to be £300-500M Capex and unknown Opex.

The UK-China collaboration is a growing area for UK CCS researchers and much of this activity is currently managed by DEFRA, with £3.5M NZEC funding. There could also be scope to greatly increase this, and include a larger and specific element of capacity building and UK training of Chinese students in UK Universities.

Many more demonstration plans have been announced in 2007-08. Many companies have now declared that they are planning CCS investments. This increased level of publicly declared interest is likely, at least in part, a result of the government competition.

No large investment decision has yet been made though. An experimental 1MW post-combustion capture plant at Aberthaw will be independently built by RWE npower.

Progressive Energy/Centrica are funding investigating development of a pre-combustion IGCC with CCS by 2012.

Global Energy has stated it wishes to re-open the Westfield gasifier as an IGCC with CCS in 2008 – but needs funding.

It seems that it will take at least 2012 until the first full CCS systems up and running in the UK.

Pre-combustion dominates, and there are as yet no plans for a UK oxyfuel plant.

The desk-study plans for CO<sub>2</sub> gathering and transport networks in Tees-side, Yorkshire, Mersey basin, and Scotland may have coordinating and catalyzing effects on capture and storage investments in those regions.

All projects listed in Table 5.2 depend on some type of funding contribution from the Government, and have been identified from news published during 2007 / 2008.

**Table 5.1 Demonstration Funding Programmes**

<b>Programme</b>	<b>Funding Agency</b>	<b>Description</b>	<b>Number of projects</b>	<b>Committed Funds</b>	<b>Period</b>	<b>Representative Annual Spend</b>
<a href="#">Carbon Abatement technology (CAT)</a>	<a href="#">BERR</a> (now TSB)	Enabling one or more pilots to go ahead in UK, within an EU context, to gain experience in CCS	To be allocated end 2006 onwards	£35m	2007 – 2011	£7
<a href="#">UK- China bilateral</a>	<a href="#">DEFRA</a> & <a href="#">BERR</a>	The project aims to demonstrate coal-fired power generation with carbon capture and storage technology in both China and the EU by 2020	Examine the viability of different technology options for the capture of carbon dioxide emissions from power generation for geological storage in China	£3.5m	2006 – 2009	£1.15m
<a href="#">CCS Competition</a>	<a href="#">BERR</a>	Competitive bids during 2008, to win state aid enabling post-combustion capture to be fitted to a new or existing coal plant, and operated before end 2014 to produce electricity and send CO <sub>2</sub> for storage.	1	Not specified £300 M capture  £500M ???	09 -14  15-20	60M  100M

**Table 5.2: Major Demonstration Projects**

Name	Description	Sub-topics covered	Total Project Cost	Public Sector Funder	Public Sector Funding	Period
Aberthaw, Wales	Retrofit. Post-combustion: first experimental 1 MW, then demonstrator >25MW. RWE npower.	Post-combustion	£8.4m			Decided, (2008) 2010
Westfield, Fife	Re-development of gasification plant. Coal, but also biomass/waste. Global Energy.	Pre-combustion	£420m			Planned, 2008 (CCS later?)
Tees Valley, Teesside	New-build 800MW IGCC. Capture with hydrogen production. Centrica, Progressive Energy, Coats and Coastal Energy. Development agency Renew Tees Valley involved.	Pre-combustion, pipeline, EOR/saline aquifer	£750m			Planned, start building 2009
Tilbury, Essex	1000 MW clean supercritical coal plant. Feasibility study. Use of Didcot power station as test facility. RWE npower.	Post-combustion	£700m			Planned, 2012-16
Blyth, Northumberland	New-build supercritical boiler. Feasibility. RWE npower	Capture-ready plant (post-combustion)				Planned, 2014
Kingsnorth, Kent	Two 800MW supercritical coal plants. E.ON	Post-combustion	£1000m			Planned
Killingholme, Humberside	New-build 450MW IGCC. Feasibility study. E.ON	Pre-combustion				Planned
Immingham, Lincolnshire	New-build 450MW IGCC. CHP. ConocoPhillips	Pre-combustion				On hold Oct 07
Hatfield, Yorkshire	New-build 900MW IGCC. Powerfuel (Kuzbassrazrezugol)	Pre-combustion				Planned
Longannet, Fife and Cockenzie, East Lothian	Retrofit with 'capture-ready' supercritical boiler at both plants. Feasibility study. Scottish Power (Iberdrola).	Post-combustion Capture-ready plants				Planned
Yorkshire and Humber region	Network. £0.1m feasibility study. Run by AMEC. Funded by the Yorkshire Forward development agency. BP, ConocoPhillips, Drax Power, E.ON, Powerfuels, Scottish	Transport. Technical and economic aspects.	100k			Underway

	and Southern and Shell support the project.					
Scotland	Network feasibility study. Managed by SCCS. Joint funding from Scottish Government and 8 companies	Transport. Storage sites, Business model	200k			Planned
Peterhead, Aberdeenshire; Miller North Sea oil reservoir	Original plan: pre-combustion, hydrogen for 350MW power station. Plan abandoned by BP in 2007, but Scottish and Southern Energy still going ahead?	Pre-combustion gas, transport, off-shore storage	>£300m			On hold as of May 07
Ferrybridge, Yorkshire	Retrofit with 500MW 'capture-ready' supercritical boiler. Scottish and Southern Energy	Capture-ready plant				On hold as of Oct 07

## 6. Research Facilities and Other Assets

[Return to Top](#)

Many organisations and universities have general facilities relating to energy, science or technology studies, which can be adapted to use for

CCS work, but there are as yet only a few UK research facilities dedicated to CCS.

**Table 6.1: Research facilities/assets**

Name	Brief description	Type of facility/asset	Scale	Annual Operating Budget
Didcot, Oxfordshire	Oxyfuel and post-combustion. Owned by RWE npower.	Test facility	0.5 MW	
Ratcliffe-on-Soar, Nottinghamshire	Oxyfuel. Owned by E.On.	Test facility	1 MW	
Aberthaw, Wales	RWE, post-combustion, coal slipstream pilot	Test facility	1 MW	

## 7. Networks

### [Return to Top](#)

Networks is here taken to mean only groupings with explicit and formal memberships. This excludes collaborative projects organised in other ways. For example, the Yorkshire-Forward-driven plan to establish a transport network, mentioned in section 5, which is supported by a distinct set of companies, but does not involve a membership as such. Research projects supported by groups of companies are not seen as more formal networks.

This covers networks in the UK only. There is substantial international activity on generic (and some UK) problems, funded and reported through networks listed in sections 8 and 9. Because of the cross-border nature of atmospheric CO<sub>2</sub>, and the generic similarity of capture technologies, and the nature of storage localities in the subsurface, the

geographic locale of the network is not critical. International exchange is expected by Demonstration plants gaining EU support.

The Trade Association CCSA was formed early in 2006, and focuses much industry expertise, but not yet onto projects. The UK Offshore Operators Association is also an important trade association in relation to CCS. Renew Tees Valley is a local collaboration in the Tees Valley between councils, but also involving companies in the area. The only academic network specific to the UK is the UKCCSC, and this arises only from the focus of a TSEC project funded by NERC.

**Table 7.1 Networks**

Network	Established	Description	Membership	Activities
<a href="#">Carbon Capture and Storage Association (CCSA)</a>	2006	Trade association spanning all industries connected with carbon capture and storage in the UK.	About 20 organisations.	Information exchange Single point industry voice
<a href="#">UK Offshore Operators Association</a>		Trade association representing North Sea exploration and production industries, both major oil companies, and contractors	30 major UK hydrocarbon companies, 15 associates	Information exchange Single industry voice Reports outlining views to Government
<a href="#">Renew Tees Valley</a>		Regional development agency. Companies also involved.	Five borough councils	New build power station with carbon capture
<a href="#">UK Carbon Capture and Storage Consortium (UKCCSC)</a>	2005-08	The UKCCSC is a consortium of engineering, technological, natural, environmental, social and economic scientists.	Academics. Individuals or research groups? Number?	Information exchange Research Public and media information Capacity building

## 8. UK Participation in EU Framework Programmes

[Return to Top](#)

Much work in the EU is undertaken by national organisations, such as Surveys, Research Institutes or Research laboratories. The UK has few of these. However, the UK participates in many EU networks. These

are addressing generic trans-national problems of combustion technology, transport, and geological storage.

**Table 8.1: EU Framework Programmes**

Project	Objectives	Action Line	Type of Action	UK Participants	Co-ordinator and partners	Total Funding	EU Funding	Duration	Annual spend
<a href="#">DECARBIT</a> : Enabling advanced pre-combustion capture techniques and plants	DECARBIT responds to the urgent need for further research and development in advanced pre-combustion capture techniques to substantially reduce emissions of greenhouse gases from fossil fuel power plants. The project will accelerate the technology development and contribute to the deployment of large scale carbon capture and storage (CCS) plants in line with the adopted European policies for emission reductions.	FP7: ENERGY-2007-5.1-01 Advanced pre-combustion capture techniques	Large-scale integrating project	ALSTOM Power Ltd, University of Ulster	<a href="#">SINTEF</a> <a href="#">ENERGIFORSKNING A/S</a> , Norway  16 partners	€15.48m	€10.22m	2008-1-1 to 2011-12-31  48 months	€2.56m
<a href="#">CESAR</a> : CO2 Enhanced Separation and Recovery	CESAR aims for a breakthrough in the development of low-cost post-combustion CO2 capture technology to provide economically feasible solutions for both new power plants and retrofit of existing power plants which are responsible for the majority of all anthropogenic CO2 emissions (worldwide, approx. 5,000 power plants emit around 11 GtCO <sub>2</sub> /year).	FP7: ENERGY-2007-5.1-03 Advanced separation techniques	Collaborative Project (small or medium scale focused project)	DOOSAN BABCOCK ENERGY LIMITED, E.ON UK PLC, RWE NPOWER PLC	<a href="#">Nederlandse Organisatie voor toegepast-natuurwetenschappelijk onderzoek - TNO</a> , Netherlands  22 partners	€6.7m	€4m	2008-02-01 to 2011-05-31  40 months	€1.2m



<a href="#">CAESAR:</a> Carbon-free Electricity by SEWGS: Advanced materials, Reactor and process design	The proposed project CAESAR is building on work currently performed with the FP6 IP CACHET. One of the four pre combustion CO <sub>2</sub> capture technologies that are being developed in CACHET is the Sorption Enhanced Water Gas Shift (SEWGS) process. The SEWGS process produces hot, high pressure H <sub>2</sub> in a catalytic CO shift reactor with simultaneous adsorption of CO <sub>2</sub> on a high temperature adsorbent.	FP7: ENERGY-2007-5.1-04 Separation techniques in gaseous fuel power generation (RTD)	Small or medium-scale focused research project	Air Products OLC, BP Exploration Operating Company Ltd	<a href="#">Energy Research Centre of the Netherlands</a>  5 partners	€3.14m	€2.26m	2008-01-01 to 2011-12-31  48 months	€0.57m
<a href="#">STRACO2:</a> Support to Regulatory Activities for Carbon Capture and Storage	STRACO2 will support the ongoing development of a comprehensive regulatory framework in the European Union for CO <sub>2</sub> capture and storage technologies (CCS) for zero emission applications. This will respond to the requirements of multi-stakeholder groups in Europe affected by these technologies and their applications both domestically in Europe and under future inclusion in emissions trading schemes and Kyoto mechanisms.	FP7: ENERGY-2007-5+6.2-01 Support to regulatory activities for CO <sub>2</sub> capture and storage	Support actions	Development Solutions Europe Ltd,	<a href="#">Bureau de recherches géologiques et minières</a> , France  9 partners	€1.04m	€0.86m	2008-01-01 to 2009-06-30  18 months	€0.57m
<a href="#">ENCAP:</a> Enhanced Capture of CO <sub>2</sub>	The objective is to develop new pre-combustion CO <sub>2</sub> -capture technologies and processes for power generation based on fossil fuels - mainly hard coal, lignite and natural gas - that are conceived as affordable and clean, and which can be integrated with sustainable energy systems.	FP6: SUSTDEV-1.2.7: M-L Capture and sequestration of CO <sub>2</sub>	Integrated project	Mitsui Babcock Alstom Power BOC University of Ulster	<a href="#">Vattenfall AB</a>  27 partners	€22.17m	€10.7m	March 2004 - March 2009	€2.14m

<a href="#">CASTOR</a> : CO <sub>2</sub> from Capture to Storage	To enable the capture and geological storage of 10% of the CO <sub>2</sub> emissions of Europe, which corresponds to about 30% of CO <sub>2</sub> emitted by European power and industrial plants. Sub-projects cover: Strategy for CO <sub>2</sub> reduction; Post-combustion capture; and CO <sub>2</sub> storage performance and risk assessment studies	FP6-SUSTDEV-1.2.7: M-L Capture and sequestration of CO <sub>2</sub>	Integrated project	Natural Environment Research Council Imperial College Mitsui Babcock Powergen	<a href="#">Institut Francais du Petrole</a>  30 partners	€15.84m	€8.5m	February 2004 – February 2008	€2.13m
<a href="#">CO<sub>2</sub>REMOVE</a> : CO <sub>2</sub> Geological Storage: Research into Monitoring and Verification Technology	The aim is to test CO <sub>2</sub> monitoring and verification technologies at real CO <sub>2</sub> injection sites, specifically Sleipner, In Salah and Snøhvit – and possibly additional sites as they begin to store CO <sub>2</sub> . At Sleipner it will continue monitoring where the SACS and CO <sub>2</sub> STORE projects left off	FP6: SUSTDEV-1.2.7 Capture and sequestration of CO <sub>2</sub>	Integrated project	Natural Environment Research Council, BP International Limited, Imperial College, Quintessa Ltd, IEA Environmental Projects Ltd	<a href="#">Nederlandse Organisatie Voor Toegepast Natuurwetenschappelijk Onderzoek - TNO</a>  23 partners	€15.05m	€8.0m	March 2006- Feb 2011	
<a href="#">CACHET</a> : Carbon Dioxide Capture and Hydrogen Production from Gaseous Fuels	CACHET aims to develop technologies to significantly reduce the cost of CO <sub>2</sub> capture from natural gas with H <sub>2</sub> production. The primary objective is to reduce the cost of CO <sub>2</sub> capture from current levels to 20-30 per tonne.	FP6: SUSTDEV-1.2.7 Capture and sequestration of CO <sub>2</sub>	Integrated Project	BP Exploration Operating Company Ltd E.ON UK PLC Air Products Plc Meggitt (UK) Ltd	<a href="#">BP Exploration Operating Company Ltd</a>  28 partners	€13.45m	€7.5m	March 2006 - March 2009	€2.5m
<a href="#">CO<sub>2</sub>SINK</a> : In-situ R&D Laboratory for Geological Storage of CO <sub>2</sub>	A better understanding of the science of CO <sub>2</sub> sequestration is needed. The CO <sub>2</sub> SINK integrated project aims at developing this basis by injection of CO <sub>2</sub> into a saline aquifer underneath the city of Ketzin near Berlin.	FP6: SUSTDEV-1.2.7: M-L Capture and sequestration of CO <sub>2</sub>	Integrated Project	University of Kent	<a href="#">GeoForschungsZentrum Potsdam</a>  13 partners	€12.68m	€8.7m	April 2004 - April 2009	€1.74m

<p><a href="#">DYNAMIS:</a> Towards Hydrogen and Electricity Production with Carbon Dioxide Capture and Storage</p>	<p>The main objective is to prepare the ground for large-scale European facilities producing hydrogen and electricity from fossil fuels with CO<sub>2</sub> capture and geological storage.</p>	<p>FP6: SUSTDEV-1.2.7 Capture and sequestration of CO<sub>2</sub></p>	<p>Integrated Project</p>	<p>Natural Environment Research Council BP International Ltd E.ON UK PLC Progressive Energy Ltd IEA Environmental Project Ltd</p>	<p><a href="#">Sintef Energiforskning A/S</a>  29 partners</p>	<p>€7.46m</p>	<p>€4m</p>	<p>March 2006 - March 2009</p>	<p>€1.3m</p>
<p><a href="#">CO2GeoNet:</a> Network of Excellence on Geological Sequestration of CO<sub>2</sub></p>	<p>CO2GeoNet (13 institutes) contains a critical mass of research activity in the area of underground carbon dioxide (CO<sub>2</sub>) storage</p>	<p>FP6-SUSTDEV-1.2.7: M-L Capture and sequestration of CO<sub>2</sub></p>	<p>Network of excellence</p>	<p>British Geological Survey Heriot-Watt University Imperial College</p>	<p><a href="#">British Geological Survey</a>  12 partners</p>	<p>Not Specified</p>	<p>€6.0m</p>	<p>April 2004 – April 2009</p>	<p>€1.2m</p>
<p><a href="#">EU GEOCAPACITY:</a> Assessing European Capacity for Geological Storage of Carbon Dioxide</p>	<p>The GeoCapacity project will focus on countries in eastern, central and southern Europe not previously covered in detail. This project will provide the data required for the Europe wide adoption of CCS.</p>	<p>SUSTDEV-1.2.7 Capture and sequestration of CO<sub>2</sub></p>	<p>Specific Targeted Research Project</p>	<p>NERC</p>	<p><a href="#">Danmarks og Groenlands Geologiske Undersoegelse</a>  26 partners</p>	<p>€3.59m</p>	<p>€1.9m</p>	<p>January 2006 - January 2009</p>	<p>€0.6m</p>

<a href="#">DESANNS</a> : Advanced separation and storage of carbon dioxide: Design, Synthesis and Applications of Novel Nanoporous Sorbents	CO <sub>2</sub> that will be critically important in the future European H <sub>2</sub> based economy. It is crucial to find a new route to capture and store CO <sub>2</sub> produced during various industrial processes with different conditions. The present project aims to initiate novel synthesis strategies for adsorbents with specific properties with respect to gases, notably carbon dioxide, and operating conditions of industrial processes.	FP6: SUSTDEV-1.2.7 Capture and sequestration of CO <sub>2</sub>	Specific Targeted Research Project	University of St Andrews University of Edinburgh The Royal Institution of Great Britain	<a href="#">Centre national de la Recherche Scientifique (CNRS)</a>  8 partners	€3.48m	€2.5m	January 2006 - January 2009	€0.8m
<a href="#">FENCO</a> : Fossil Energy Coalition	FENCO-ERA networks national R&D activities in fossil energy conversion and CO <sub>2</sub> capture and storage. It provides a platform for information exchange on fossil fuel R&D activities at national and regional level; establishes a common knowledge base for zero emission power plants; and strengthens the European R&D and demonstration infrastructure through joint programming, management, personnel exchange and targeted integration activities.	FP6	ERANET	DTI Future Energy Solutions (AEA Technology)	<a href="#">Forschungszentrum Jülich Projektträger Jülich</a>  17 partners	€3.00m	€3.00m	Jun 2005 – May 2009	€0.75m
<a href="#">ISCC</a> : Innovative In Situ CO <sub>2</sub> Capture Technology for Solid Fuel Gasification	The proposed project aims on exploiting this potential to produce a gas stream in the regeneration process consisting of >95% CO <sub>2</sub> .	FP6: SUSTDEV-1.2.7: M-L Capture and sequestration of CO <sub>2</sub>	Specific Targeted Research Project	University of Ulster	<a href="#">Universitaet Stuttgart</a>  14 partners	€2.91m	€1.9m	January 2004 - January 2007	€0.63m

<a href="#">C3-CAPTURE:</a> Calcium Cycle For Efficient and Low Cost CO <sub>2</sub> Capture in fluidised bed systems	The project aims on developing a dry CO <sub>2</sub> <i>capture</i> system for atmospheric and pressurized fluidised bed boilers	FP6: SUSTDEV-1.2.7: M-L <i>Capture</i> and sequestration of CO <sub>2</sub>	Specific Targeted Research Project	Cranfield University	<a href="#">Universitaet Stuttgart</a> 12 partners	€2.72m	€1.8m	September 2005 - September 2008	€0.6m
<a href="#">HY2SEPS:</a> Hybrid hydrogen - carbon dioxide separation systems	The main goal of this project is the development of a hybrid membrane/ Pressure Swing Adsorption (PSA) H <sub>2</sub> /CO <sub>2</sub> separation process, which will be a part of a fossil fuel de-carbonisation process used for the pre-combustion CO <sub>2</sub> capture	FP6: SUSTDEV-1.2.7 Capture and sequestration of CO <sub>2</sub>	Specific Targeted Research Project	Imperial College Process Systems Enterprise	<a href="#">Foundation for Research and Technology Hellas</a> 7 partners	€2.53m	€1.56m	September 2005 - October 2008	€0.52m
<a href="#">INCA-CO<sub>2</sub>:</a> International Co-operation Actions on CO <sub>2</sub> Capture and Storage	Aimed at strengthening European excellence and enhancing technical competitiveness of Europe in the area of CO <sub>2</sub> Capture and Storage (CCS)	FP6: SUSTDEV-2003-1.2.9: M-L Support to the strategic objectives of the programme	Specific Support Action	Alstom Power BP International Ltd NERC	<a href="#">Institut Francais du Petrole</a> 10 partners	€0.71m	€0.44m	October 2004 - October 2007	€0.15m
<a href="#">ZEFPP:</a> Zero Emission Fossil Fuel Power Plants	The initial scope of the Platform aims at identifying and removing the obstacles to the creation of highly efficient power plants with near-zero emissions which will drastically reduce the environmental impact of fossil fuel use, particularly coal. This will include CO <sub>2</sub> capture and storage, as well as clean conversion technologies leading to substantial improvements in plant efficiency, reliability and costs.		European Technology Platform	<a href="#">Alstom</a> ; <a href="#">British Geological Society</a> ; <a href="#">Mitsui Babcock</a> ; <a href="#">Shell Gas and Power</a> (Advisory Council)	<a href="#">European Commission</a>			2004 -	

<p><a href="#">GESTCO</a>: European potential for geological storage of co2 from fossil fuel combustion</p>	<p>The principal objective of GESTCO is to make a major contribution to the reduction in CO2 emissions to the atmosphere and so ensuring Europe a continued stable supply of affordable and environmentally acceptable energy.</p>	<p>FP5: Economic and Efficient Energy for a Competitive Europe</p>	<p>Cost sharing contracts</p>	<p>Natural Environment Research Council</p>	<p><a href="#">Geological Survey of Denmark and Greenland</a>  10 partners</p>	<p>€3.80m</p>	<p>€0.19m</p>	<p>2000-03-01 to 2003-03-01  36 months</p>	<p>€0.063m</p>
<p><a href="#">RECOPOL</a>: Reduction of co2 emission by means of co2 storage in coal seams in the Silesian coal basin of Poland (management of ghg emissions) recopol</p>	<p>In this project the feasibility of greenhouse gas emission reduction by CO2 storage in subsurface coal seams is studied. Locally produced CO2 or flue gas from a power plant is injected in the coal at a selected test site in the Silesian Coal Basin (Poland), while CH4 is produced simultaneously. The CH4 can be used as fuel for clean energy generation, without net CO2 emissions.</p>	<p>FP5: Cleaner Energy Systems, including Renewable Energies, Reduction of local and global environment degrading emissions</p>	<p>Cost sharing contracts</p>	<p>CRE Group Ltd</p>	<p><a href="#">Netherlands Organisation for Applied Scientific Research - TNO</a>  11 partners</p>	<p>€3.74m</p>	<p>€1.71m</p>	<p>2001-11-01 to 2005-07-31  45 months</p>	<p>€0.46m</p>

<p><a href="#">NASCENT:</a> Natural analogues to the storage of co2 in the geological environment (NASCENT)</p>	<p>NASCENT will address key issues of geological CO2 sequestration by using natural CO2 occurrences as analogues for geological repositories of anthropogenic CO2. The issues include the long-term safety and stability of storage underground and the potential environmental effects of leakage from an underground reservoir. The project will provide clear information to assess and support management of the potential risks to the environment and thus, it will make a direct contribution to the environmental protection objectives of the programme.</p>	<p>FP5: Cleaner Energy Systems, including Renewable Energies, Reduction of local and global environment degrading emissions</p>	<p>Cost sharing contracts</p>	<p>BP Exploration Operating Company Ltd, CRE Group Ltd, NATURAL ENVIRONMENT RESEARCH COUNCIL</p>	<p><a href="#">Natural Environment Research Council</a>  12 partners</p>	<p>€3.29m</p>	<p>€1.86m</p>	<p>2001-01-01 to 2004-04-30  40 months</p>	<p>€0.56m</p>
<p><a href="#">GRACE:</a> Grangemouth advanced CO2 Capture Project (GRACE)</p>	<p>GRACE sets out a two-year programme that aims to develop technologies that will achieve a step change in the cost of capture and separation of carbon dioxide. In addition to further development of existing technologies, the project will research and develop new technologies from their current concept stages to feasible working models.</p>	<p>FP5: Cleaner Energy Systems, including Renewable Energies, Reduction of local and global environment degrading emissions</p>	<p>Cost sharing contracts</p>	<p>BP Exploration Operating Company Ltd</p>	<p><a href="#">BP Exploration Operating Company Ltd</a>  9 partners</p>	<p>€3.20m</p>	<p>€2.15m</p>	<p>2001-12-01 to 2003-12-31  25 months</p>	<p>€0.93m</p>

<a href="#">SACS2</a> : Saline aquifer co2 storage (2) - demonstration in the Sleipner field ('sacs2')	SACS2 (This application) will monitor and verify the distribution of the CO2, bubble for two more years. Methods will be tested for prediction of the CO2 behaviour thousands of years into the future. RESULTS: Through monitoring and verification of integrated use of existing models, the SACS2 project will provide a scientifically based "Best-Practice-Manual".	FP5: Economic and Efficient Energy for a Competitive Europe	Cost sharing contracts	CRE Group Ltd, Natural Environment Research Council, BP Exploration Operating Company Ltd	<a href="#">BP Exploration Operating Company Ltd</a> 12 partners	€3.03m	€1.20m	2000-04-01 to 2002-10-31 31 months	€0.46m
<a href="#">CO2STORE</a> : On-land long term saline aquifer co2-storage (CO2STORE)	EU is required to reduce its CO2 emissions by 8% by 2008-2012, later deeper cuts are foreseen. CO2 underground storage is one of the few options that can meet these obligations. The present project investigates four new potential cases for CO2-reservoirs, mainly on land. It will continue reservoir simulations and study geochemical reactions to develop final-fate prediction models. This will be supported by new seismic observations. At the same time gravimetrics is introduced as a new method better suited on land. This proposal builds directly on the Thermie/5FP SACS2 project results, which involved monitoring and modelling the injection of CO2 into the Utsira Sand aquifer, at Sleipner gas field, offshore Norway.	FP5: Cleaner Energy Systems, including Renewable Energies	Cost sharing contracts	NATURAL ENVIRONMENT RESEARCH COUNCIL, BP EXPLORATION OPERATING COMPANY LTD, IEA ENVIRONMENTAL PROJECTS LTD, PROGRESSIVE ENERGY LIMITED	<a href="#">Statoil Asa</a> 18 partners	€2.50m	€1.21m	2003-02-01 to 2006-01-31 36 months	€0.40m



<p><a href="#">WEYBURN</a>: The weyburn CO<sub>2</sub> monitoring project (weyburn)</p>	<p>This project will enhance the knowledge and understanding of the underground sequestration of CO<sub>2</sub>, especially where associated with enhanced oil recovery (EOR), and develop and enhance monitoring techniques to ensure safe and stable underground storage. The proposed project will study and monitor the injection and sequestration of the CO<sub>2</sub> at the Weyburn oil field (Saskatchewan, Canada) as an integral part of a long-term IEA-facilitated project.</p>	<p>FP5: Cleaner Energy Systems, including Renewable Energies, Reduction of local and global environment degrading emissions</p>	<p>Cost sharing contracts</p>	<p>CRE Group Ltd, Quintessa Ltd., NATURAL ENVIRONMENT RESEARCH COUNCIL</p>	<p><a href="#">Natural Environment Research Council</a> 7 partners</p>	<p>€2.25m</p>	<p>€1.19m</p>	<p>2001-01-01 to 2004-06-30 42 months</p>	<p>€0.34m</p>
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<p><a href="#">CO2NET2:</a> Carbon dioxide thematic network 2002-2005</p>	<p>CO2 Thematic Network will facilitate the development of CO2 capture and storage as a safe, technically feasible, socially acceptable mitigation option. This is one component of an overall strategy for the provision of a safe, secure, climate neutral energy supply for the European Union. Elimination technology development is included.</p>	<p>FP5: Cleaner Energy Systems, including Renewable Energies</p>	<p>Thematic network contracts</p>	<p>Heriot-Watt University, Natural Environment Research Council, ABB Alstom Power UK Ltd., BP Exploration Operating Company Ltd., Technology Initiatives Ltd, Quintessa Ltd., Imperial College London, IEA Environmental Projects Ltd., Progressive Energy Limited, Texaco North Sea U.K.</p>	<p><a href="#">Statoil ASA</a> 27 partners</p>	<p>€2.11m</p>	<p>€1.40m</p>	<p>2002-11-01 to 2005-10-31  36 months</p>	<p>€0.47m</p>
<p><a href="#">ICBM:</a> Development of advanced reservoir characterisation and simulation tools for improved coalbed methane recovery</p>	<p>This project aims at establishing an understanding of the basic scientific phenomena of CO<sub>2</sub>-CH<sub>4</sub> adsorption, desorption, diffusion and flow in coal seams. The objectives of the project would be achieved through experimental and theoretical work to be carried by the project partners.</p>	<p>FP5: Key action Economic and Efficient Energy for a Competitive Europe, Cost effective and more efficient exploration and production of hydrocarbons</p>	<p>Cost-sharing contracts</p>	<p>Imperial College London, Wardell Armstrong Ltd, BP Exploration Operating Company Ltd.</p>	<p><a href="#">Imperial College London</a> 5 partners</p>	<p>€1.55m</p>	<p>€1m</p>	<p>2000-10-01 to 2004-03-31  42 months</p>	<p>€0.33m</p>

<a href="#">Carbon dioxide capture and sequestration in geological storage technology network development programme, 2000-2001</a>	<p>Extensive external interest in two EU projects on CO<sub>2</sub> sequestration into geological storage; SACS, an industrial scale demonstration into a saline aquifer and GESTCO, assessing the potential for geological storage in Europe, demanded immediate action, resulting in the development of this technology development awareness and networking proposal, CO<sub>2</sub>NET, to promote and facilitate the diffusion, transfer, exploitation and broader use of the projects' results to help meet Kyoto emissions reduction demands.</p>	<p>FP5: Cleaner Energy Systems, including Renewable Energies, Reduction of local and global environment degrading emissions</p>	<p>Preparatory, accompanying and support measures</p>	<p>CRE Group Ltd, Technology Initiatives Ltd</p>	<p><a href="#">Technology Initiatives Ltd</a> 3 partners</p>	<p>€0.22m</p>	<p>€0.13m</p>	<p>2000-12-01 to 2002-05-31  18 months</p>	<p>€0.083m</p>
<p><a href="#">GOSAC: Global Ocean Storage of Anthropogenic Carbon</a></p>	<p>GOSAC aims to improve understanding of the ocean's role in the global carbon cycle via comparison of ocean carbon-cycle models. GOSAC will help speed the development of these models which are used to test and compare paradigms of how the ocean's carbon-cycle operates. With its diverse group of models, GOSAC will also provide uncertainty estimates to accompany model predictions.</p>	<p>FP4: Basic processes of the climate system</p>	<p>Cost-sharing contracts</p>	<p>University of Southampton, National Environment Research Council</p>	<p>Centre National De La Recherche Scientifique  8 partners</p>			<p>1997-2001  40 months</p>	

## 9. International Initiatives

### [Return to Top](#)

The UK is involved in many of the key international activities. This is by participation of major industry players (e.g. BP led the Carbon Capture project), or by very active Government membership (e.g. BERR within CSLF). The IEA Greenhouse Gas Programme has commissioned a series of reports and formed networks covering all aspects of CCS from power stations, to transport costs, worldwide storage, and geological aspects. There is substantial international activity on generic (and some UK) problems, funded and reported through world networks. The UK has also signed bilateral understandings on CCS with Norway and

with China. Key research leaders internationally are perceived to be: Norway, Canada, Australia, and USA. Very few (if any) of these have significant involvement by UK Universities. A difference between the USA and rest of the world is the duality of funding to Federal laboratories and projects, together with Regional Partnerships of states to investigate CCS.

Table 9.1 includes international activities with UK involvement.

**Table 9.1: International Activities**

Name	Type	Description	UK Contact Point
<a href="#">Carbon Capture Project (CCP)</a>	Large industry association	8 global companies collaborating in generic research 3 countries USA, Norway, \$24 M 2005 –07, CSLF endorsed	Gardiner Hill (BP)
<a href="#">IEA Greenhouse Gas R&amp;D - Capture and Storage of CO<sub>2</sub></a>	Membership of multi national corporations and nations	The IEA Greenhouse Gas R&D Programme (IEA GHG) is an international collaboration. It is funded by large member companies (hydrocarbon exploration and power generators), and by national governments. Research topics are elicited from the member groups, and reports undertaken, many of which are publicly available. The group co-ordinates several international networks (subscription), and operates technology workshops. A good R&D database is available. Harry Audus is the general Manager of the Programme.	Gardiner Hill (BP)
<a href="#">Carbon Sequestration Leadership Forum (CSLF)</a>	Political and technical world organisation	Government-led network of 22 countries focused on development of improved cost-effective technologies for the separation and capture of carbon dioxide for its transport and long-term storage. Technical interaction of world leading energy companies, key forum for policy. Originated by USA, established in 2003. Trans-national standards and approaches to CCS	<a href="#">BERR</a>
<a href="#">International</a>	Subscription network	2000 Topic led by IEA GHG, 62 major companies and some Universities.	<a href="#">John Topper</a>

<a href="#">Network for CO2 Capture</a>		Efficient post-combustion CO2 capture from flue gas, by solvent, membrane, or solid sorbent	
<a href="#">Monitoring Network</a>	Subscription network	2004 led by IEA GHG, 60 organisations, CCS Monitoring techniques, CCS Monitoring programmes	<a href="#">Angela Manancourt</a>
<a href="#">Oxy-Fuel Combustion Network</a>	Subscription network	2005 led by IEA GHG, forum for organisations with interest in the development of Oxy-Fuel Combustion Technology	<a href="#">John Topper</a>
<a href="#">Risk Assessment Network</a>	Subscription network	2005 led by IEA GHG 40 organisations from 9 countries and regulators. Can risk assessment provide the answers regulators require?	<a href="#">Angela Manancourt</a>
<a href="#">Well Bore Integrity Network</a>	Subscription network	2005, led by IEA GHG, 33 organisations from 6 countries, Integrity of boreholes to retain CO2 for long periods.	<a href="#">Angela Manancourt</a>
The Zero Emission Coal Alliance (ZECA) Corporation	Subscription corporation	Established in 1999, comprises 18 companies and research organisations. Canadian led but links to USA and international. Focus is on hydrogen and power from clean coal.	
<a href="#">Zero Emissions Platform (ZEP)</a>	EU technology platform	2005. Funded by the European Commission. Formal members (sponsors) are large industrial corporations. Participation also from NGOs, scientists and environmentalists. Focus is entirely on CCS.	