

## UKERC ENERGY RESEARCH ATLAS: CARBON CAPTURE AND STORAGE

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# UKERC

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## 1. Overview

### Characterisation of the field

Most forecasts predict that fossil fuels will play a major role in meeting global energy demand to 2030 or even 2050. As well as coal, oil and gas, this is likely to include increasing production from unconventional sources such as tar sands. In this context, carbon management (or 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). CCS deployment in the UK could provide working examples of technology, projects and financial systems for other parts of the world, while helping to meet national policy targets for 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 and enhanced oil recovery.

Different research and industry communities are involved in these: expertise in carbon capture in universities and industry, the electricity supply industry and power systems equipment manufacturers, and skills related to CO<sub>2</sub> transport, subsurface injection, and enhanced oil recovery in universities, research institutes and the oil and gas sector. 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. Pre-combustion capture is potentially an accessible and low-cost method of large scale hydrogen production. Oxyfuel capture is the least mature method, and is under development at large laboratory scale. Developed oxyfuel plant could enable widespread clean and efficient use of abundant coal resources. Transport of large quantities of CO<sub>2</sub> by pipeline is well established in the US (onshore) and in oil and gas company pipelines (offshore). A North Sea project in the Norwegian Sleipner field has demonstrated the feasibility of CO<sub>2</sub> injection since 1996, but a number of research challenges remain. Finally, although enhanced oil recovery (EOR) is well established in the US, there is very little UK experience with this technology (the benefit of EOR from additional oil may be financially offset by the greater cost of operating an EOR offshore facility).

## Research Challenges

Key questions are the determination of costs, the prediction of leakage rates for the time spans involved, the ability to verify and monitor site performance and improved determination of public acceptability.

- Development of full-scale electricity generation plant, with full-scale CO<sub>2</sub> capture as part of operation process. The needs will differ for needs of pre-combustion (improved membrane separation CO<sub>2</sub>), post-combustion (better amine solvents or alternatives), oxyfuel (cheaper oxygen separation from air, better membranes for CO<sub>2</sub> separation).
- Determination of costs: Capex e.g. of building new generation plants, retrofitting old plants, installing pipelines, infrastructure at storage sites. Opex including Enhanced Oil Recovery platform costs, monitoring, verification protocols for all CCS. Also, distances between CO<sub>2</sub> sources and sinks can be critical cost barriers to entry, evaluation of pipeline availability, staged entry opportunities, and optimisation of shared facilities is important financially.
- Improving assessment of the availability of storage space, hydrocarbon 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, and trialled.

- Enhanced Oil Recovery – how will geo-engineering methods be adapted for offshore use? How 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 volume issues need to be addressed to enable low cost storage by local communities and smaller emitters. National and supranational licensing, participation of CCS in emissions trading schemes, local, national and supranational environmental protection issues, international treaties such as OSPAR and the London Convention and its protocol.
- Public acceptance is a potential showstopper, but will be less important offshore. More investigation is needed to guide approaches to local communities affected.

## 2. Capabilities Assessment

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. It is uncertain if the UK still retains all the capability to make a complete coal or gas plant domestically.

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

expertise in fabrication of offshore equipment is strong. There are large and SME companies to fill many niches.

Financing and managing 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) 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 investigation</li> <li>• Coal-fired boilers</li> <li>• Turbines: gas and steam</li> <li>• Onshore pipes</li> <li>• Offshore pipes</li> <li>• Finance of projects</li> <li>• Carbon trading</li> </ul>	<ul style="list-style-type: none"> <li>• World-leading offshore hydrocarbon techniques</li> <li>• Manufacturer within world top 10</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> </ul>
<b>Medium</b>	<ul style="list-style-type: none"> <li>• Entire coal power station</li> <li>• Entire gas power station</li> <li>• Offshore EOR mechanical and geo-engineering</li> </ul>	<ul style="list-style-type: none"> <li>• International competition</li> <li>• International competition</li> <li>• Will be needed to develop for EOR in UK, techniques could then be applied internationally</li> </ul>
<b>Low</b>	<ul style="list-style-type: none"> <li>• Membranes to separate CO<sub>2</sub></li> <li>• Solvent CO<sub>2</sub> capture</li> <li>• CO<sub>2</sub> pipeline</li> <li>• Design of capture add-on</li> </ul>	<ul style="list-style-type: none"> <li>• Large potential specialist materials</li> <li>• Large market for new variants</li> <li>• Will be needed for EOR in UK</li> <li>• Will be needed in UK</li> </ul>

### **3. Basic and applied strategic research**

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 strongly involved in EU and worldwide networks. The DTI has funded a series of studies emerging from its coal technology and clean coal programmes – now in Energy sources/sustainable technologies. These are by a variety of contractors, often including 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 NERC TSEC programme; the UKCCSC coordinates that research activity, and this is by far the largest

cluster of UK research activity. There is no training capacity specifically directed to CCS, but individual academics with UKCCSC have related PhD students. UKERC has experience of monitoring CCS developments, cross-compared to other energy technologies. 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 cluster for that speciality.

Information in Table 3.2 was solicited by e-mail to individual academics within the UKCCSC. This gives a high estimate of people involved in CCS research. A search of academic web-sites for CCS activity would yield much lower numbers of personnel involved, in many cases zero for individual institutions.

**Table 3.1: Research Funding**

<b>Funding stream</b>	<b>Funding Agency</b>	<b>Description</b>	<b>Committed Funds</b>	<b>Period</b>	<b>Representative Annual Spend</b>
<a href="#">TSEC carbon management</a>	<a href="#">NERC</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	£2.6m	04 - 08	£650k
<a href="#">UK Energy Research Centre</a>	<a href="#">NERC/EPSC/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 Sustainability	£350k (of £12m)	04 -09	£70k
Responsive Mode	<a href="#">EPSC/NERC</a>	No grants specifically identified	0		
<b>TOTAL</b>			<b>£4.95m</b>		

**Table 3.2: Key Research Providers**

<b>Name</b>	<b>Description</b>	<b>Sub-topics covered</b>	<b>No of staff<sup>1</sup></b>	<b>Field</b>
<a href="#">Plymouth Marine Laboratory</a> (PML)	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> <li>• Simulation modelling</li> </ul>	5 fulltime research staff, 9 total	Biological Sciences
<a href="#">School of Biosciences, 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>• 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, 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 PD, 2 MSc	Built Environment
<a href="#">Policy Research in Engineering, Science and Technology (PREST) ?</a>	PREST undertakes research and advisory work, and provides research training in the fields of science and technology policy and management studies through postgraduate	<ul style="list-style-type: none"> <li>• Stakeholder perceptions</li> <li>• Public perceptions</li> <li>• Policy analysis of CCS from socio-political and institutional</li> </ul>	2 staff, 2 PD	Business and Management Studies

<sup>1</sup> PD is post-doctoral researcher

<a href="#">Manchester Business School,</a> <a href="#">University of Manchester</a>	degrees and topic-orientated short courses.	<p>perspectives</p> <ul style="list-style-type: none"> <li>• Energy scenarios and their assessment</li> <li>• Sustainability appraisal</li> </ul>		
<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
<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 seam</li> <li>• Phase equilibria of fluids</li> </ul>	4 staff, 4 PhD	Chemical Engineering
<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 Biodiversity	<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 PD, 1 PG	Earth Sciences  Environmental Sciences
<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 PhD	Earth Sciences  Environmental Sciences
<a href="#">School of Geosciences,</a>	The School is a leading international centre	<ul style="list-style-type: none"> <li>• Reactions of CO<sub>2</sub> in reservoirs</li> </ul>	5 staff, 3 PD, 1	Earth Sciences

<a href="#">University of Edinburgh</a>	for research into GeoSciences.	<ul style="list-style-type: none"> <li>Natural analogues to CCS</li> <li>CO<sub>2</sub> leakage rates</li> </ul>	PhD	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>	Research spans both Earth science and Earth engineering. 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> in reservoirs</li> <li>CO<sub>2</sub> in coal beds</li> <li>CO<sub>2</sub> storage security</li> </ul>	2 staff c. 5 RA/PhD	Earth Sciences  Environmental Sciences
<a href="#">School of Earth and Environment</a> and the <a href="#">Rock Deformation Research Group</a> ,  <a href="#">University of Leeds</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, 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, we offer a wide range of services to hydrocarbon and mineral industries worldwide.	<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>Faults</li> <li>Geochemical reaction kinetics</li> <li>Ion exchange capacity of reservoir rocks</li> </ul>	2 staff, 1 MSc, 1 PhD	Earth Sciences  Environmental Sciences
<a href="#">School of Civil Engineering and Geoscience</a> and <a href="#">School of Marine Science and Technology</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,	<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> </ul>	4 Staff 2 PD	Earth Sciences  Environmental Sciences

<a href="#">University of Newcastle</a>	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>• Gis technology : routing studies</li> <li>• Ship design</li> <li>• Offshore engineering</li> </ul>		Civil Engineering
<a href="#">British Geological Survey (BGS)</a>	BGS hosts the largest cluster of projects in Europe addressing underground geological storage of CO <sub>2</sub> . BGS has carried out research into CO <sub>2</sub> sequestration/avoidance, providing information on the UK's onshore energy resources and defining reservoir characteristics and researching into underground fuel storage (natural gas & hydrogen) and geothermal energy.	<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 and 7 for non-CCS CO <sub>2</sub> .	Earth Sciences Environmental Sciences Geography
<a href="#">Scottish Centre for Carbon Storage</a>	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	<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</li> </ul>	7 academic staff 4 PD 3 PhD 6 MSc	Earth Sciences Environmental Sciences Chemistry Physics Applied Mathematics Statistics and Operational Research General Engineering Education

		<p>simulation of CO<sub>2</sub> -brine-hydrocarbon</p> <ul style="list-style-type: none"> <li>• Fluid migration modelling through overburden and in aquifers</li> <li>• Natural analogue studies to determine durability and processes</li> <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,</a> <a href="#">University of Aberdeen</a>	<p>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.</p>	<ul style="list-style-type: none"> <li>• Social processes and CCS</li> </ul>	2 staff, 1 PD	Economics and Econometrics
<a href="#">Department of Electrical and Electronic Engineering,</a> <a href="#">Imperial College</a>	<p>Research activities within the Department are organised broadly into five groups: Circuits &amp; Systems, Communications &amp; Signal Processing, Control &amp; Power, Intelligent Systems &amp; Networks and Optical &amp; Semiconductor Devices</p>	<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,</a> <a href="#">Cranfield University,</a>	<p>Key areas of research relate to materials, manufacturing, natural resources and sustainable systems.</p>	<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,</a> <a href="#">Heriot-Watt University</a>	<p>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 academic links around the world. Most of the research projects are supported by several industrial partners, sometimes in collaboration with public sector funding.</p>	<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> <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>	<p>11 staff, 6 PhD</p>	<p>General Engineering</p>
<a href="#">School of Chemical, Environmental and Mining Engineering,</a> <a href="#">University of Nottingham</a>	<p>SChEME is home to some really ground breaking 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.</p>	<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>	<p>Total (not all CCS): 6 staff, 8 PD, &gt;12 PG</p>	<p>General Engineering</p>
<a href="#">School of Geography,</a> <a href="#">University of Nottingham</a>	<p>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.</p>	<ul style="list-style-type: none"> <li>• Effects of CO<sub>2</sub> leakage on flora</li> <li>• Climate change</li> </ul>	<p>2 staff</p>	<p>Geography  Environmental Sciences</p>
<a href="#">Department of Mechanical Engineering,</a> <a href="#">Imperial College</a>	<p>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.</p>	<ul style="list-style-type: none"> <li>• Power plant design</li> <li>• Oxyfuel combustion</li> <li>• Biomass co-combustion</li> <li>• Novel capture technologies</li> </ul>	<p>4 staff 2 RA 4 PhD</p>	<p>Mechanical, Aeronautical and Manufacturing Engineering</p>
<a href="#">Robert Gordon University</a>	<p>RGU in Aberdeen is focused on work relevant to the offshore and energy industries.</p>	<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> </ul>	<p>3 staff 2 PDRA 1 PhD</p>	<p>Mechanical, Aeronautical and Manufacturing</p>

		<ul style="list-style-type: none"><li>• Hydrogen Production</li><li>• Dehydration of hydrogen</li><li>• Membrane Reactor Research</li><li>• Synthesis Gas Operation</li></ul>		Engineering
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#### 4. Applied research

Applied research is provided by a range of consultancy companies and organisations with expertise in the sectors of technology appraisal, environment, or geoscience. The DTI and IEA GHG programme have been key strategic funders. Substantial activity is occurring in other countries' national laboratories and research organisations. 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.

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 appears to be no focused campaign to evaluate and provide new information.

Potential research providers were identified from membership of the CCS trade association in early May 2006 (CCSA), and from attendance at CCS-related meetings. Note that some companies who do conduct research into CCS may have chosen not to supply information for commercial reasons.

**Table 4.1: Research Funding**

<b>Programme</b>	<b>Funding Agency</b>	<b>Description</b>	<b>Committed Funds</b>	<b>Period</b>	<b>Representative Annual Spend</b>
<a href="#">Carbon Trust Technology Acceleration</a>	<a href="#">The Carbon Trust</a>	The Carbon Trust is an independent not for profit company set up by the UK Government with support...	Nil	-	Nil
<a href="#">Energy Sources Cleaner fossil fuels technology</a>	<a href="#">DTI</a>	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="#">DTI Clean Coal and Carbon Abatement Technologies (CAT strategy)</a>	<a href="#">DTI</a>	Component part of DTI Energy, focused on carbon-free power from fossil fuel. This includes Enhanced Oil Recovery, which does not seem to be tackled by DTI Oil and Gs	£35m	07-11	£7m
<b>TOTAL</b>					

**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 and 7 for non-CCS CO <sub>2</sub> .	R&D science and engineering  Other non-departmental public body
<a href="#">E.ON Energy</a>	E.ON UK is the UK's largest integrated energy company – generating and distributing electricity, and retailing electricity and gas – and is part of the E.ON group, the world's largest investor-owned energy services provider, with ambition	<ul style="list-style-type: none"> <li>• Powerplant</li> </ul>	£1.3m in 2006, not including project development activities	Electricity and gas

	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. Acknowledged as being at the top internationally. Global Commercial Litigation Law Firm of the Year 2005	<ul style="list-style-type: none"> <li>• Legal and legislative aspects of CCS</li> </ul>	3 lawyers	Legal activities
<a href="#">Mitsui Babcock</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 company with offices and locations across all the major energy markets. Major coal boiler R&D and manufacturing facility at Renfrew UK	<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 £1m p.a.	R&D science and engineering  Manufacturing  Consulting engineers
<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 Carbon Services</a>	A leading oilfield services provider, delivering superior	<ul style="list-style-type: none"> <li>• Reservoir modelling of CO<sub>2</sub> storage fields</li> </ul>	2	Energy extraction

	results and improved E&P performance for oil and gas companies around the world. Schlumberger Carbon Services are in Abingdon			
<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 of gas; electrical and utility contracting; and telecoms. HQ Perth, Scotland.	<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

## 5. Development and Demonstration Funding

Demonstration funding has been allocated by the DTI, as part of its CAT strategy. This was initially £25m, and then was increased by the Chancellor to £35m in a pre-budget statement 2005. This is tiny compared to the £100m minimum requested by the DTI advisory board, and tiny compared to the true cost of a power station of £800-1,000m, or the USA FutureGen initiative of \$500m Federal finance. The China initiative appears to be operated by DEFRA, and is a preliminary evaluation. 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.

No Demonstration projects exist in the UK from the private sector, although several proposals have emerged during 2005 and 2006. All projects listed in Table 5.2 depend on some type of additional change to the funding regime by the Government.

**Table 5.1 Development and Demonstration Funding**

<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="#">DTI</a>	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	Nil
<a href="#">UK- China bilateral</a>	<a href="#">DEFRA</a> & <a href="#">DTI</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
EU Risk-Sharing Finance Facility (RSFF)  RDI@eib.org +352 4379 1 Kim Kreilgaard	European Investment Bank. division for Research, Development &	Dedicated to European Technology Platforms (ETP) which should also allow support of activities with above average risk profiles  Especially targeting University involvement	To become active in FP7		2007 - 12	€ 10 Bn overall € 10 -20 M per project per year

	Innovation					
<b>TOTAL</b>				<b>£38.5m</b>		

**Table 5.2: Major Demonstration Projects**

<b>Name</b>	<b>Description</b>	<b>Sub-topics covered</b>	<b>Funding</b>	<b>Period</b>
<a href="#">Peterhead/Miller zero carbon electricity demo</a>	The proposal would convert natural gas to hydrogen and carbon dioxide gases, then use the hydrogen gas as fuel for a 350MW power station, and export 1.3 MtCO <sub>2</sub> /yr to the Miller North Sea oil reservoir for increased oil recovery and ultimate storage. Decision end 2006	CCS, EOR, Hydrogen	\$600m	2006 - 10
<a href="#">RWE NPower</a>	Tilbury, Essex, 1000 MW clean supercritical coal plant, with CO <sub>2</sub> capture and storage. Use of Didcot power station as test facility.	Clean coal CCS Offshore storage	£700m	2012 - 16
<a href="#">Tees Valley</a>	Tees-side 800MW IGCC new build with CCS. Pre-combustion capture, generation of hydrogen. Storage, pipelined offshore to saline aquifer or EOR. Progressive Energy with Centrica	IGCC, Clean coal, Hydrogen, Pre-combustion, carbon capture, offshore storage, aquifer, EOR	\$1.5b	2007 - 09

## **6. Research Facilities and Other Assets**

No UK facilities dedicated to CCS are known to exist. Many organisations and Universities have general facilities relating to energy, science or technology studies, which can be adapted to use for CCS work.

## 7. Networks

This covers networks in the UK only but 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 in nature of storage localities in the subsurface, the geographic locale of the network is perhaps less important than for some other technologies, and international exchange is more expected.

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. The Trade Association CCSA was formed early in 2006, and focuses much industry expertise, but not yet onto projects.

**Table 7.1 Networks**

<b>Network</b>	<b>Established</b>	<b>Description</b>	<b>Membership</b>	<b>Activities</b>
<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, no University representation	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 Association company	Five borough councils	New build power station with carbon capture

## 8. UK Participation in EU Framework Programmes

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. Images explaining funding and timelines of EU projects focused on CCS are available from DYNAMIS or on [www.co2storage.org.uk/CCS\\_Research/](http://www.co2storage.org.uk/CCS_Research/)

**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
<b>COACH</b>	Clean coal use as feed for polygeneration in China (power, hydrogen, synthetic fluids). Coal plant with CCS and EOR	FP6		BGS Imperial College DTI	Institute Francias de petrole francois.kalaydjian@ifp.fr 12 EU and 8 chinese partners			11/06 – 09  plant operational by 2015	
<a href="http://www.zero-emissionplatform.eu">ZEFPP Zero Emission Fossil Fuel Power Plants</a>  <a href="http://www.zero-emissionplatform.eu">www.zero-emissionplatform.eu</a>	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 CO2 capture and storage, as well as clean conversion technologies leading to substantial improvements in plant efficiency, reliability and		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 -	

	costs.								
<b>FENCO Fossil Energy Coalition</b>	FENCO-ERA networks national R&D activities in fossil energy conversion and CO2 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</a> <a href="#">Projektträger Jülich</a>  17 partners	€3.00m	€3.00m	Jun 2005 – May 2009	€0.75m
<b>INCA-CO2</b> - International Co-operation Actions on CO2 Capture and Storage	Aimed at strengthening European excellence and enhancing technical competitiveness of Europe in the area of CO2 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
<b>CO2GeoNet</b> Network of Excellence on Geological Sequestration of CO2	CO2GeoNet (13 institutes) contains a critical mass of research activity in the area of underground carbon dioxide (CO2) storage	FP6- SUSTDEV-1.2.7: M-L Capture and sequestration of CO2	Network of excellence	British Geological Survey Heriot-Watt University Imperial College	<a href="#">British Geological Survey</a>  12 partners	Not Specified	€6.0m	April 2004 – April 2009	€1.2m
<b>CASTOR</b> CO2 from	To enable the capture	FP6-	Integrated	Natural	<a href="#">Institut Francais du Petrole</a>	€15.84m	€8.5m	February	€2.13m

Capture to Storage	and geological storage of 10% of the CO2 emissions of Europe, which corresponds to about 30% of CO2 emitted by European power and industrial plants. Sub-projects cover: Strategy for CO2 reduction; Post-combustion capture; and CO2 storage performance and risk assessment studies	SUSTDEV-1.2.7: M-L Capture and sequestration of CO2	project	Environment Research Council Imperial College Mitsui Babcock Powergen	30 partners			2004 – February 2008	
<a href="http://www.cachetco2.eu/">CACHET</a> - Carbon Dioxide Capture and Hydrogen Production from Gaseous Fuels	CACHET aims to develop technologies to significantly reduce the cost of CO2 capture from natural gas with H2 production. The primary objective is to reduce the cost of CO2 capture from current levels to 20-30 per tonne.	FP6: SUSTDEV-1.2.7 Capture and sequestration of CO2	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
CO2reMoVe	The aim is to test CO2 monitoring and verification technologies at real CO2 injection sites, specifically Sleipner, In Salah and Snøhvit – and possibly additional sites as they begin to store CO2. At Sleipner it will continue monitoring where the SACS and CO2STORE	FP6	Integrated project					2006-	

	projects left off								
<a href="#">CO2SINK</a> - In-situ R&D Laboratory for Geological Storage of CO2	A better understanding of the science of CO2 sequestration is needed. The CO2SINK integrated project aims at developing this basis by injection of CO2 into a saline aquifer underneath the city of Ketzin near Berlin.	FP6: SUSTDEV- 1.2.7: M-L Capture and sequestration of CO2	Integrated Project	University of Kent	<a href="#">GEOFORSCHUNGSZENTRUM POTSDAM</a>  13 partners	€12.68m	€8.7m	April 2004 - April 2009	€1.74m
<a href="#">DYNAMIS</a> - Towards Hydrogen and Electricity Production with Carbon Dioxide Capture and Storage  <a href="http://www.dynamis-hypogen.com">http://www.dynamis-hypogen.com</a>	The main objective is to prepare the ground for large-scale European facilities producing hydrogen and electricity from fossil fuels with CO2 capture and geological storage.	FP6: SUSTDEV- 1.2.7 Capture and sequestration of CO2	Integrated Project	Natural Environment Research Council BP International Ltd E.ON UK PLC Progressive Energy Ltd IEA Environmental Project Ltd	<a href="#">SINTEF ENERGIFORSKNING A/S</a>  29 partners	€7.46m	€4m	March 2006 - March 2009	€1.3m
<a href="#">ENCAP</a> - Enhanced Capture of CO2	The objective is to develop new pre-combustion CO2-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 CO2	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="#">C3-CAPTURE</a> - Calcium	The project aims on	FP6:	Specific	Cranfield	<a href="#">Universitaet Stuttgart</a>	€2.72m	€1.8m	September	€0.6m

Cycle For Efficient and Low Cost CO2 Capture in fluidised bed systems	developing a dry CO2 <i>capture</i> system for atmospheric and pressurized fluidised bed boilers	SUSTDEV-1.2.7: M-L <i>Capture</i> and sequestration of CO2	Targeted Research Project	University	12 partners			2005 - September 2008	
<a href="#">DESANNS</a> - Advanced separation and storage of carbon dioxide: Design, Synthesis and Applications of Novel Nanoporous Sorbents	In the future European H2 based economy. It is crucial to find a new route to capture and store CO2 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 CO2	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="#">EU GEOCAPACITY</a> - Assessing European Capacity for Geological Storage of Carbon Dioxide	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.	SUSTDEV-1.2.7 Capture and sequestration of CO2	Specific Targeted Research Project	NERC	<a href="#">DANMARKS OG GROENLANDS GEOLOGISKE UNDERSOEGELSE</a>  26 partners	€3.59m	€1.9m	January 2006 - January 2009	€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)	FP6: SUSTDEV-1.2.7 Capture and sequestration	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

	H2/CO2 separation process, which will be a part of a fossil fuel de-carbonisation process used for the pre-combustion CO2 capture	of CO2							
<a href="#">ISCC</a> - Innovative In Situ CO2 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% CO2.	FP6: SUSTDEV-1.2.7: M-L Capture and sequestration of CO2	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="#">Advanced Zero Emissions Power Plant (AZEP)</a> <b>1.1 Oxy fuel</b>	Development of zero emission gas turbine-based, power generation process to reduce local and global emissions in a cost-effective way	FP5	Integrated Project	Alstom Power UK University of Ulster			€9.3m	2001-04	€3.1m
<a href="#">CO2net</a>	European Network of researchers, developers and users of CO2 technology, including 51 companies or organisations and covering 18 countries. It comprises an R&D project database and conducts annual information meetings.	FP5	Subscription organisation				€2.1m	2002	
<a href="#">CRUST</a>	CO2 Re-use through						€12m	2002-05	

	Underground Storage								
<a href="#">GESTCO</a>	Assessing European Potential for Geological Storage of CO2 From Fossil fuel Combustion	FP5	Integrated Project					2001-02	
<a href="#">GOSAC</a>	Global Ocean Storage of Anthropogenic Carbon: Ocean storage CO2	FP5	Integrated Project	Southampton Oceanography Centre				1998-2001	40 months
<a href="#">GRACE</a>	Grangemouth Advanced CO2 Capture Project. Sub-topics covered include chemical looping and hydrogen separation by membranes.	FP5	Integrated Project	BP Exploration Operating Company Ltd Royal Institute of Technology		€3.2m		2002 - 2004	€1.6m
<a href="#">ICBM</a>	Investigation into the Basic Scientific Phenomena of CO2 Injection and Retention in Coal for CO2 Storage and Enhanced Coal Bed Methane Recovery	FP5	Integrated Project	Imperial College, London Wardell Armstrong Ltd, BP UK				2000-04	
<a href="#">NASCENT</a>	Natural Analogues for the Geological Storage of CO2	FP5	Integrated Project	BGS, BP UK		€3.3m		2001-03	€1.1m
<a href="#">NGCAS</a>	The Development of Next Generation Technology for the Capture and		Integrated Project	BP UK		€0.46m		2001-04	€0.15m

	Geological Storage of Carbon Dioxide from Combustion Processes.								
<a href="#">SACS</a>	Large-scale demonstration of CO2 injection and storage in undersea deep saline aquifer	FP5	Integrated Project	BGS			€45m	1998-2002	

## 9. International Initiatives

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. DTI 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: International Activities**

<b>Name</b>	<b>Type</b>	<b>Description</b>	<b>UK Contact Point</b>
<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 CO2</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.	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="#">DTI</a>
<a href="#">International Network for CO2 Capture</a>	Subscription network	2002 Topic led by IEA GHG, 62 major companies and some Universities. Efficient post-combustion CO2 capture from flue gas, by solvent, membrane, or solid sorbent	<a href="#">John Topper</a>
<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>
<a href="#">The Zero Emission Coal Alliance (ZECA)</a> 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.	