

UKERC ENERGY RESEARCH ATLAS: CARBON CAPTURE AND STORAGE

(version 10 February 2008)

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Version 1.2 published 2006, compiled by Stuart Haszeldine and Mark Wilkinson

This version 2, reviewed externally, modified by Nils Markusson, Stuart Haszeldine Jan 2008

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1. Overview

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 CO₂ — the IPCC estimate that application of CCS worldwide could halve new CO₂ emissions (IPCC, 2005). In the 2006 IEA World Energy Outlook (Beyond Alternative Policy), CCS is a requirement to remove about 20% of CO₂ 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 CO₂ 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 CO₂ from fossil fuels, transport of liquefied CO₂, 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 CO₂ 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 CO₂ combustion gases to be efficiently separated. Cheaper separation of oxygen from air is required.

Transport of large quantities of CO₂ 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 CO₂ pipe. since 1996, but a number of research challenges remain.

Geological injection is offshore is proven only by the local Utsira experiment. Although enhanced oil recovery (EOR) with CO₂ 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 CO₂ 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 CO₂ 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 CO₂ 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.
- CO₂ 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 CO₂ and H₂. Oxyfuel: cheaper O₂ separation from air, better membranes for CO₂ separation, chemical looping. Performance of capture during plant ramp-up and ramp-down in a flexible price market.
- Transport: distances between CO₂ 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 CO₂ 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 CO₂ sealing vertically by mudrock and by faults
- Enhanced Oil Recovery – how will geo-engineering methods be adapted for offshore use? Can gravity drive of CO₂ be used cheaply for improved production of total oil resource?
- Investigation of natural CO₂ 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 CO₂ 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 engagement is persistently neglected

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. 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

UK Capability	Area	Market Potential
High	<ul style="list-style-type: none"> • Subsurface geological and engineering • Coal-fired supercritical boilers • Oxyfuel burners • Air separation units for oxyfuel • Turbines: gas and steam • Onshore pipes • Offshore pipes • Finance of projects • Carbon trading • Design of capture add-on 	<ul style="list-style-type: none"> • World-leading offshore hydrocarbon techniques • Manufacturer within world top 5 • Manufacturers research within world top 5 • Excellent chemical engineering research, weak industry • Two /more world leading companies • Methane established technology • UK subsidiaries of global companies • City of London is a world centre + banks • World centre • Innovative companies and researchers
Medium	<ul style="list-style-type: none"> • Coal power station • Gas power station • CO2 compression • Offshore EOR mechanical and geo-engineering • Gasifiers of solid fuel 	<ul style="list-style-type: none"> • International competition • International competition • One strong company • Will be needed to develop for EOR in UK, techniques could then be applied internationally • Research active, and industry heritage from chemical industry and national coal and power laboratories
Low	<ul style="list-style-type: none"> • Membranes for separation of CO₂, O₂ • Solvent CO₂ capture • CO₂ pipeline • Design of "capture ready" add-on 	<ul style="list-style-type: none"> • Excellent materials research, Large specialist potential • Large market for new variants, no focus • Will be needed for EOR in UK • Will be needed in UK, China

3. Basic 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 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 dominates 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
TSEC carbon management	NERC/EPSC/ESRC	The UK Carbon Capture and Storage Consortium (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 ₂ 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
Scottish Centre for Carbon Storage SCCS	Scottish Funding Council, University of Edinburgh, Heriot-Watt University	Start-up funds for key research staff, to become self-funding within 4 years. Focus on CO ₂ storage, EOR, aquifer injection, leakage and monitoring. Industry-funded sponsor group	£2.6m	04 - 08	£650k
Scottish Centre for Carbon Capture	EPSC Scottish Funding Council Scottish Enterprise Universit of Edinburgh Heriot-Watt University	Creating capacity by grouping existing staff and recruiting new staff, to apply chemical engineering and process engineering to CO ₂ 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
Nottingham University	EPSC	Grouping existing staff on Energy and new recruitment to a Centre for Innovation in Carbon Capture and Storage CICCS	£1.1M	07-12	£210k
UK Energy Research Centre	NERC/EPSC/ESRC	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	£350k (of £12m)	04 -09	£70k

		on carbon management in Future Sources of Energy, and CCS Environmental Impacts within Sustainability.			
Annual calls for proposal	<u>BCURA</u>	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	<u>NERC</u>	University of Cambridge lead an academic consortium on fundamental geochemistry of CO ₂ -rock interaction.	5M	08-13	1M
TOTAL			£23 m		£ 6.2 m

Table 3.2: Key Research Providers

Name	Description	Sub-topics covered	No of staff¹	Field
Centre for Sustainable Technologies, School of the Built Environment, University of Ulster	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"> • Simulation of capture and combustion 	4 staff and 2 PhD	Architecture and the Built Environment
Plymouth Marine Laboratory (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"> • Ocean ecology • Ocean currents • Effects of atmospheric and marine CO₂ on ecosystems • Environmental chemistry • QSAR-based modelling • Biomarker development and validation 	5 full time research staff, 9 total	Biological Sciences

¹ PD is post-doctoral researcher

		<ul style="list-style-type: none"> • Remote/satellite surveillance • Interpretation of complex information • Simulation, modelling 		
School of Biosciences, University of Nottingham	<p>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.</p>	<ul style="list-style-type: none"> • Detection of soil CO₂ • Effects of enhanced CO₂ on biota • Dispersion of CO₂ release 	5 people	Biological Sciences
<p>* School of Construction Management and Engineering, University of Reading,</p>	<p>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.</p>	<ul style="list-style-type: none"> • Fossil fuel lifecycle cost modelling • Fossil fuel emissions • Integrated multi-disciplinary optimization of energy systems • Socio-Techno-Economic Modelling 	1 staff, 1 PD, 2 MSc	Built Environment
<p>Policy Research in Engineering, Science and Technology (PREST) Manchester Business School, University of Manchester</p>	<p>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.</p> <p>These staff are also part of Tyndall (North)</p>	<ul style="list-style-type: none"> • Stakeholder perceptions • Public perceptions • Policy analysis of CCS from socio-political and institutional perspectives • Energy scenarios and their assessment • Sustainability appraisal 	2 staff, 3 PD	Business and Management Studies
<p>* Judge Business School, University of Cambridge</p>	<p>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</p>	<ul style="list-style-type: none"> • Public acceptability • Stakeholder analysis • Integrated assessment • Policy evolution • International environmental negotiations 	1 staff, 1 RA, 1 PhD	Business and Management Studies

	International Business and Management and Cambridge University Health.			
Sussex Energy Group / SPRU - Science and Technology Policy Research, University of Sussex.	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"> • CCS economics and incentives for innovation and deployment • Corporate capabilities in CCS technologies 	4 staff	Business and Management Studies / Politics and International Studies
* Department of Chemical Engineering and Chemical Technology, Imperial College	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"> • CCS in coal seams • Phase equilibria of fluids 	4 staff, 4 PhD	Chemical Engineering
School of Chemical Engineering and Advanced Materials, Newcastle University	The School received a 5-rating in RAE2001. The School's research mission is to deliver 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.	<ul style="list-style-type: none"> • CO₂ separation from combustion processes using ceramic membranes. 	9 staff, 4 PD, 10 PhD. These numbers include non-CCS research.	Chemical Engineering
Chemical Engineering,	Research interests in the Department of Chemical Engineering cover a broad range	<ul style="list-style-type: none"> • Fluidised reaction systems for clean coal plants 	3 staff	Chemical Engineering

University of Cambridge	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"> • CO₂ separation 		
Institute for Materials and Processes, University of Edinburgh	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"> • CO₂ separation 	3 staff 3 PD 6 PhD	Chemical Engineering Metallurgy and Materials
* Department of Earth Sciences, University of Bristol,	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"> • Passive seismic monitoring • Predicting 4d seismic properties • Linked seismic and geomechanical modelling 	2 staff, 1 PD, 1 PG	Earth Sciences Environmental Sciences
* Department of Earth Sciences University of Cambridge	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"> • Modelling and imaging CO₂ flows at Sleipner • Thermodynamics, kinetics and geochemical signatures of reaction processes in reservoirs • Geochemical/isotopic monitoring of reactions 	3 staff 1 PD 1 PhD	Earth Sciences Environmental Sciences
* School of Geosciences,	The School is a leading international centre	<ul style="list-style-type: none"> • Reactions of CO₂ in reservoirs 	5 staff,	Earth Sciences

University of Edinburgh	<p>for research into GeoSciences. An industry sponsored group exists</p> <p>These staff are part of the Scottish Centre for Carbon Storage</p>	<ul style="list-style-type: none"> • Natural analogues to CCS • CO₂ leakage rates • Monitoring of CO₂ • Detection of dissolved CO₂ • Whole system CCS • CPD courses CCS 	7 PD, 6 PhD	Environmental Sciences
Earth Surface Dynamics Research Group, Department of Geographical and Earth Sciences University of Glasgow	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"> • Subsurface CO₂ flow • Effects of faults • CO₂ leakage effects 	1 staff, 1 PhD	Earth Sciences Environmental Sciences
Department of Earth Science and Engineering, Imperial College	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"> • CO₂ storage in hydrocarbon reservoirs and aquifers • CO₂ multiphase flow properties • CO₂ in coal beds • CO₂ storage security 	3 staff, c. 7 RA/PhD not directly engaged on CCS	Earth Sciences Environmental Sciences
* School of Earth and Environment and the Rock Deformation Research Group, University of Leeds	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, RDR offers a wide range of services to hydrocarbon and mineral industries worldwide.	<ul style="list-style-type: none"> • Sub-surface flow of fluids • Multi-phase flow in rocks • Mineral cementation • Fracturing and fluid flow • Faults and seal • Geochemical reaction kinetics • Ion exchange capacity of reservoir rocks 	2 staff, 1 PD 1 MSc, 1 PhD	Earth Sciences Environmental Sciences
School of Civil Engineering and Geoscience and School of Marine Science and	The traditional research strengths of the School of Civil Engineering and Geosciences (CEG) lie in the fields of Civil Engineering,	<ul style="list-style-type: none"> • Geological seal integrity • Pipeline engineering (offshore/onshore) 	4 Staff 2 PD	Earth Sciences Environmental

Technology, University of Newcastle	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"> • Hydraulic and risk analysis • Phase modelling • GIS technology : routing studies • Ship design • Offshore engineering 		Sciences Civil Engineering
British Geological Survey (BGS)	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 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 ₂ storage in sub-sea geological formations. Part of BGS Keyworth is contracted to BERR 2008-09 to review CCS competition technical issues and bids.	<ul style="list-style-type: none"> • CCS monitoring and verification • UK and generic CO₂ storage capacity research • Geochemical experimentation into CO₂ water/rock reactions under subsurface conditions • CO₂ clathrates 	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
Scottish Centre for Carbon Storage	This grouping is funded by the Scottish Higher Education Funding Council to apply and extend established world-class	<ul style="list-style-type: none"> • Experimental PVT studies of CO₂ with varying hydrocarbons • Hydrates and clathrates in 	21 academic staff 7 PD 15 PhD	Earth Sciences Environmental

	<p>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>	<p>porous media and pipes</p> <ul style="list-style-type: none"> • Seismic processing and interpretation • Novel seismic survey acquisition and processing • Micro-seismicity in real-time to determine fluid migration • Rock physics experiments of mudrock seal deformation and re-seal • Petrographic investigation of CO₂-brine and rock interaction • Fluid migration tracing by natural isotopes and artificial tracers • Geochemical interaction simulation of CO₂ -brine-hydrocarbon • Fluid migration modelling through overburden and in aquifers • Natural analogue studies to determine durability and processes • Mudrock seal petrology, and permeability modelling • Integration with UK energy research networks: renewables, fossil, nuclear • Regional assessment of aquifers, structures and seals 	6 MSc	<p>Sciences</p> <p>Chemistry</p> <p>Physics Applied Mathematics</p> <p>Statistics and Operational Research</p> <p>General Engineering</p> <p>Education</p>
<p>* Business School, University of Aberdeen</p>	<p>University of Aberdeen Business School (UABS) was formed by a merger of the departments of Accountancy-Finance, Economics, Property and Management.</p>	<ul style="list-style-type: none"> • Social processes and CCS 	2 staff, 1 PD	<p>Economics and Econometrics</p>

	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.			
* Department of Electrical and Electronic Engineering, Imperial College	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"> National Grid simulation 	1 staff, 1 RA	Electrical and Electronic Engineering
* School of Applied Sciences, Cranfield University, Institute of Petroleum Engineering, Heriot-Watt University	Key areas of research relate to materials, manufacturing, natural resources and sustainable systems. 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. These staff are listed as Scottish Centre for Carbon Storage	<ul style="list-style-type: none"> Gas cleaning Fuel-related processes 	3 total	General Engineering
School of Chemical Engineering, Heriot-Watt University	Research focused on principles of novel carbon capture or CO2 separation	<ul style="list-style-type: none"> Geophysics Reservoir characterisation Flow in porous media PVT and reservoir fluids, Tracers Gas hydrates Hydrocarbon recovery processes, EOR, EGR Geo and rock mechanics Reservoir chemistry and production CO₂ Storage 	11 staff, 6 PhD	General Engineering
* School of Chemical, Environmental and Mining Engineering,	SChEME is home to novel research in the areas of microwave processing to extract rare and valuable minerals, green chemistry, clean and green water,	<ul style="list-style-type: none"> Ionic solvents Membranes Gas-liquid separation CO₂ capture Low temperature absorption Membranes Oxy-fuel firing 	4 staff 2 PhD	General engineering
			Total (not all CCS): 6 staff, 8 PD, >12 PG	General Engineering

University of Nottingham	nanotechnology, magnetic levitation and carbon dioxide capture to reduce the risk of global warming.			
CICCS – Centre for Innovation in Carbon Capture and Storage, University of Nottingham	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"> • Cleaner coal • CO₂ capture • Light harvesting • Mineral carbonation • Storage • Monitoring • Public acceptability, regulatory issues and economy 	16 staff (not all full time)	<p>General Engineering</p> <p>Mathematics</p> <p>Bioscience</p> <p>Geography</p> <p>Earth Science</p>
School of Engineering, Energy Technology Centre Cranfield University	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, structures and machine systems.	<ul style="list-style-type: none"> • Modelling of combustion and heat transfer • CO₂ separation 	1 staff ?? PDRA ?? PhD ?? MSc	General engineering ??
Energy and Resources Research Institute, Leeds University	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"> • Modelling of Pulverised Coal Combustion 	3 staff 2 PhD ??	General engineering ??
* School of Geography, University of Nottingham	The School's research community is organised into five Research themes: Cultural and historical geography, environmental management and policy,	<ul style="list-style-type: none"> • Effects of CO₂ leakage on flora • Climate change 	2 staff	<p>Geography</p> <p>Environmental Sciences</p>

	geographical information science, new economic geographies, environmental and geomorphological sciences.			
Centre for Law and the Environment, University College London	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"> • Analysis of the key legal questions arising from CCS activities 	3 staff	Law
* Department of Mechanical Engineering, Imperial College	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"> • Power plant design • Supercritical coal plant • Oxyfuel combustion • Biomass co-combustion • Carbon capture, retrofiting • Novel capture technologies 	4 staff 2 RA 4 PhD	Mechanical, Aeronautical and Manufacturing Engineering
* Robert Gordon University	RGU in Aberdeen is focused on work relevant to the offshore and energy industries.	<ul style="list-style-type: none"> • Membrane separation of CO₂ flue gas • Acid Gas Removal from Natural Gas Streams • Hydrogen Production • Dehydration of hydrogen • Membrane Reactor Research • Synthesis Gas Operation 	3 staff 2 PDRA 1 PhD	Mechanical, Aeronautical and Manufacturing Engineering
Department of Materials, Imperial College	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"> • Ceramic oxygen separation membranes for CCS • Partial oxidation membranes for Pre-Combustion De-Carbonisation • Ash and coal properties in oxyfuel combustion 	2 Staff, 1 PG, some UG project students	Metallurgy and Materials

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. 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
DTI Clean Coal and Carbon Abatement Technologies (CAT strategy)	TSB (formerly BERR)	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
Energy Sources Cleaner fossil fuels technology	BERR	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			
Greenhouse Gas R&D Programme (IEA GHG)	IEA	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 ₂ reduction			
TOTAL					

Table 4.2: Key Research Providers

Name	Description	Sub-topics covered	Scale of operation	Sector
* Air Products	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"> • Cryogenics • Materials 	UK CCS budget 3m USD	Manufacturing
British Geological Survey	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"> • Geology • Infrastructure • Carbon capture and storage • International policy advice • Reservoir Characterisation, Storage & Production • Regional Subsurface Structure • Gas Storage • Onshore Hydrocarbon & Coal Resources 	16 staff (research and technical), 1 PhD. Also 4 staff for hydrates 7 for non-CCS CO ₂ .	R&D science and engineering Other non-departmental public body
Doosan Babcock Energy	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"> • Capture-ready supercritical coal-fired boilers • Oxy-fuel firing of coal CCS • Amine scrubbing • Integration of CC into power plant design, retrofits 	10+ personnel Budget £2m p.a. Whole Technology Centre 250 staff	R&D science and engineering Manufacturing Consulting engineers

	company with offices and locations across all the major energy markets. Major coal boiler R&D and manufacturing facility at Renfrew UK.			
Environmental Resources Management Ltd	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.	<ul style="list-style-type: none"> • Policies, laws, regulations and incentives. 	20 - 30 people with CCS expertise	Management Consulting ²
E.ON Energy	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 services provider, with ambition to becoming the world's leading power and gas company.	<ul style="list-style-type: none"> • Capture • Storage • Transportation • Utilisation areas 	<p>Around £550k not including project development activities</p> <p>Approximately 6 full time people (Around 12 part time people)</p>	Electricity and gas
* Hammonds	Hammonds is a leading	Regulatory regime:	c.12 (not full time)	Legal activities

² ERM describe themselves as an environmental consultancy, and from their reply clearly cover a broader area than just management consulting.

	commercial law firm with offices throughout the UK, Europe and in Asia	<ul style="list-style-type: none"> • Long-term liability • Monitoring • Carbon crediting • Regulatory incentives/ obstacles • Pipeline regulations 		
Herbert Smith	<p>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.</p> <p>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.</p>	<ul style="list-style-type: none"> • Treatment of CCS under the EU ETS • Interface with environmental legislation • International law requirements and incentives (eg. marine and climate change conventions) • Offshore decommissioning obligations • Planning issues • On and offshore pipeline regulation • Project development including: corporate structures, fuel supply and off-take arrangements, feed arrangements and financing • Development and regulation of power plants • Gas storage 	6-8 lawyers currently engaged on CCS related matters.	Legal activities
ILF Consulting Engineers Ltd	ILF is an international design consultant specialising in the transportation and storage of all hydrocarbons and water. This includes pipelines, terminals, underground and above ground storage and safety monitoring systems. ILF has designed over 2000 pipelines around the world	<ul style="list-style-type: none"> • Pipelines • Optimisation along the supply chain • Underground gas storage. 	€ 100 000	<p>Consulting Engineers</p> <p>Management Consulting</p>

	which includes the transportation of high CO2 content gases and gases in the supercritical phase. ILF also has some design and operational experience of gas storage in on-shore aquifers.			
* Norton Rose	International lawyers specialising in corporate finance, financial institutions, energy and utilities, technology and transport.	<ul style="list-style-type: none"> • Legal aspects of CCS 	5 lawyers	Legal activities
* Schlumberger 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"> • All CO2 engineering services • Reservoir modelling of CO₂ storage fields • Wireline detection of CO₂ • Monitoring technologies • Cement technologies 	2	Energy extraction
* Scottish & Southern	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"> • Gas fired CCS plants • Coal fired CCS plants • Integrated gasification • Coal-bed methane • Legal, environment • Health & Safety 	c. 10 people	Electricity and gas
RWE	Npower is part of the German RWE group	<ul style="list-style-type: none"> • Experimental slipstream capture of CO₂ 	?2	Electricity and gas

5. Development and Demonstration Funding

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

Gobal 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 CO₂ 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 Development and Demonstration Funding

Programme	Funding Agency	Description	Number of projects	Committed Funds	Period	Representative Annual Spend
Carbon Abatement technology (CAT)	BERR (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
UK- China bilateral	DEFRA & BERR	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
CCS Competition	BERR	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 CO2 for storage.	1	Not specified £300 M capture £500M ???	09 -14 15-20	60M 100M
TOTAL				£38.5m		App. £8m

Table 5.2: Major Demonstration Projects - proposed, none are actual in 2008

Name	Description	Sub-topics covered	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, Coots 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 and Southern and Shell support the project.	Transport. Technical and economic aspects.	100k	Underway
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

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
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

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 CO₂, 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
Carbon Capture and Storage Association (CCSA)	2006	Trade association spanning all industries connected with carbon capture and storage in the UK.	About 20 organisations.	Information exchange Single point industry voice
UK Offshore Operators Association		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
Renew Tees Valley		Regional development agency. Companies also involved.	Five borough councils	New build power station with carbon capture
UK Carbon Capture and Storage Consortium (UKCCSC)	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

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	Co-ordinator	UK Participant	Funding	Duration	Annual spend
Advanced Zero Emissions Power Plant (AZEP) Oxy fuel	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
CO2 Storage in Aquifers, CASTOR	A major reduction in CO ₂ capture costs, to advance the general acceptance of the overall concept in terms of storage performance (capacity, residence time), storage security and environmental acceptability, to start the development of an integrated strategy connecting capture, transport and storage options for Europe - new solvents for post-combustion capture - pilot plant (1 ton CO ₂ /hour)	FP6	Integrated project		BGS, Imperial, Powergen, Mitsui Babcock,	€8.5m	2004 -08	€2.1m
CO2Geonet	The network contains a critical mass of research activity in the area of underground CO ₂ storage. It is co-ordinated by the British Geological Survey.	FP6	Network of Excellence		BGS, Heriot-Watt, Imperial College (13 EU institutes, by	€6m	2004-09	€1.2m

	Activities include integrating EU CCS activity, influencing national research agendas, funding CCS research and seeking funds.				invitation)			
CO2net	European Network of researchers, developers and users of CO ₂ 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	
CO2reMoVe	The aim is to test CO ₂ monitoring and verification technologies at real CO ₂ injection sites, specifically Sleipner, In Salah and Snøhvit – and possibly additional sites as they begin to store CO ₂ . At Sleipner it will continue monitoring where the SACS and CO2STORE projects left off	FP6	Integrated project				2006-	
CO2Sink	Provide an in situ laboratory for the testing of geological storage of CO ₂ . The chosen location is an anticline formerly used for natural gas storage close to Ketzin, west of Berlin, Germany	FP6	Integrated project		University of Kent	€8.7m	2004-09	€1.74m
CRUST	CO ₂ Re-use through Underground Storage					€12m	2002-05?	
Enhanced Capture of CO2 (ENCAP)	ENCAP aimed at identifying new pre-combustion CO ₂ Capture Technologies that meet	FP6	Integrated project		Alstom Mitsui Babcock University of	€9.8m	2004-09	€2m

	the target of at least 90% CO ₂ capture and 50% CO ₂ capture cost reduction				Ulster			
GeoCapacity	"Assess the European Capacity for Geological Storage of Carbon Dioxide" Project aims at quantifying the CO ₂ storage capacity of the EU and spreading disseminate CCS knowledge to new accession countries and beyond.	FP6	Integrated Project		BGS	€1.9m	2006-08	€0.63m
GESTCO	Assessing European Potential for Geological Storage of CO ₂ From Fossil fuel Combustion	FP5	Integrated Project				2001-02?	
GOSAC	Global Ocean Storage of Anthropogenic Carbon : Ocean storage CO ₂	FP5	Integrated Project		Southampton Oceanography Centre		1998-2001	40 months
GRACE	Grangemouth Advanced CO ₂ 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
ICBM	Investigation into the Basic Scientific Phenomena of CO ₂ Injection and Retention in Coal for CO ₂ Storage and Enhanced Coal Bed Methane Recovery	FP5	Integrated Project		Imperial College, London Wardell Armstrong Ltd, BP UK		2000-04	
ISCC	Innovative In Situ CO ₂ Capture Technology for Solid Fuel Gasification Oxy fuel firing of brown coal to H ₂	FP6	Specific Targeted Research Project?	Univeristy of Stuttgart	Northern Ireland	€2.0m	2004 - 2006	€0.7m
NASCENT	Natural Analogues for the Geological Storage of CO ₂	FP5	Integrated Project		BGS, BP UK	€3.3m	2001-03	€1.1m
NGCAS	The Development of Next		Integrated		BP UK	€0.46m	2001-04	€0.15m

	Generation Technology for the Capture and Geological Storage of Carbon Dioxide from Combustion Processes.		Project					
SACS	Large-scale demonstration of CO ₂ 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. 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
Carbon Capture Project (CCP)	Large industry association	8 global companies collaborating in generic research 3 countries USA, Norway, \$24 M 2005 –07, CSLF endorsed	Gardiner Hill (BP)
IEA Greenhouse Gas R&D - Capture and Storage of CO2	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)
Carbon Sequestration Leadership Forum (CSLF)	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	BERR
International Network for CO2 Capture	Subscription network	2000 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	John Topper
Monitoring Network	Subscription network	2004 led by IEA GHG, 60 organisations, CCS Monitoring techniques, CCS Monitoring programmes	Angela Manancourt

Oxy-Fuel Combustion Network	Subscription network	2005 led by IEA GHG, forum for organisations with interest in the development of Oxy-Fuel Combustion Technology	John Topper
Risk Assessment Network	Subscription network	2005 led by IEA GHG 40 organisations from 9 countries and regulators. Can risk assessment provide the answers regulators require?	Angela Manancourt
Well Bore Integrity Network	Subscription network	2005, led by IEA GHG, 33 organisations from 6 countries, Integrity of boreholes to retain CO2 for long periods.	Angela Manancourt
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.	
Zero Emissions Platform (ZEP)	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.	