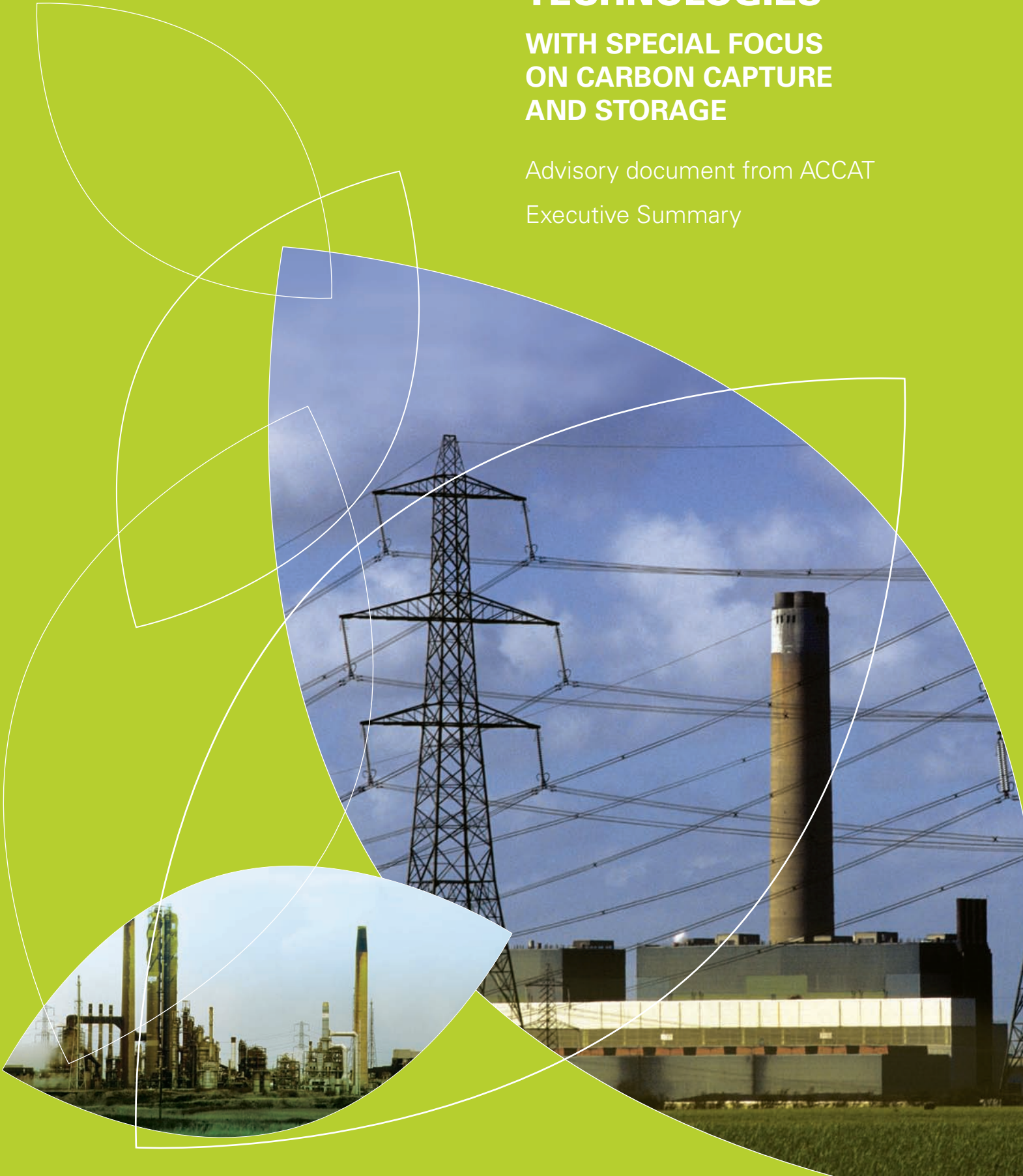


ACCELERATING THE DEPLOYMENT OF CARBON ABATEMENT TECHNOLOGIES

WITH SPECIAL FOCUS
ON CARBON CAPTURE
AND STORAGE

Advisory document from ACCAT
Executive Summary



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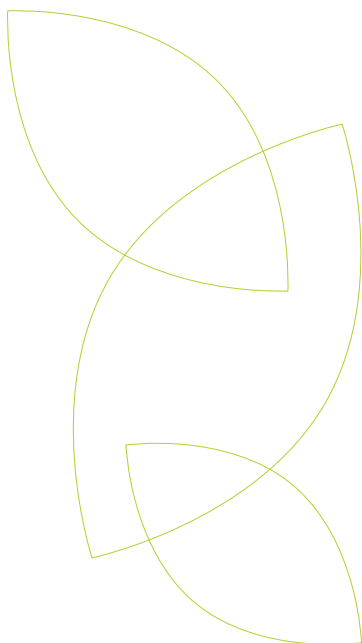


ACCAT ADVISORY STRATEGY

FOREWORD

This report on “Accelerating the Deployment of Carbon Abatement Technologies” has been produced by the Government’s Advisory Committee on Carbon Abatement Technologies in response to a growing urgency to achieve low emissions of carbon dioxide from fossil fuelled power generation. In particular, many countries and international organisations, including the EU and the G8 energy ministers are calling for the deployment of carbon capture and storage (CCS) by 2020. The UK’s Committee on Climate Change in its December 2008 report, discusses the timing of the contribution from CCS and policy towards it (p.190) and says *“It is not therefore prudent to assume that CCS is likely to make a major contribution to the achievement of emission reductions in the first three budget periods. **Instead the key issue is how policy during those periods can best be designed to facilitate a major take-off of CCS in the 2020s”.***

This report presents a UK strategy for achieving commercial deployment of CCS by 2020 and as such, the report is very timely. I hope it will provide useful input to the Government and other national and international bodies in the formulation of their strategies. The advisory committee strongly supports the actions and recommendations given in the report and we urge the Government and industry to adopt them; action is needed now.



I would like to thank all my colleagues on the committee for their hard work in putting this document together during a period of intense activity. The security of energy supply and reducing our impact on the environment are key issues for all of us. These are urgent matters for the UK energy industry, which if it is to have any significant impact, must be active and successful in both national and global markets. Currently, there is a lot of debate about these issues; I hope this document can make a contribution to the debate and also help define the required strategy.

This report is the Executive Summary; the full report will be on the DECC/BERR website: <http://www.berr.gov.uk/whatwedo/energy/sources/sustainable/carbon-abatement-tech/page19502.html>

A handwritten signature in black ink, appearing to read 'Nick Otter', with a horizontal line underneath it.

Nick Otter, Chair ACCAT

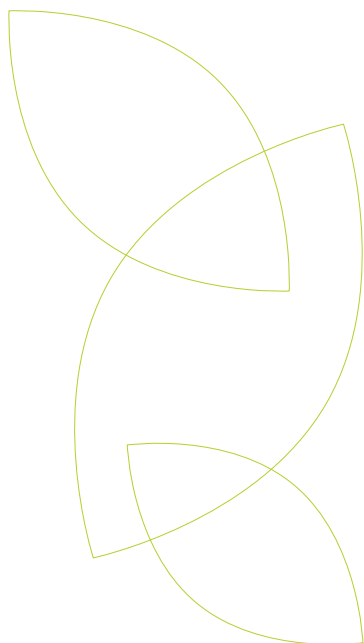
WHERE WE ARE WITH CARBON ABATEMENT TECHNOLOGIES AND OUR VISION FOR 2020

BACKGROUND

Fossil fuels currently provide the bulk of the energy for modern life and most projections show fossil fuels continuing to dominate energy supply well into the century, to 2050 at least. Fossil fuels will continue to underpin the security of electricity supply in the UK well beyond 2020 and towards 2050, irrespective of the degree of implementation of renewables or nuclear power. However, the carbon dioxide (CO₂) from combustion of fossil fuels is the main gas causing climate change and ocean acidification.

Fossil-fuel based carbon abatement technologies (CATs) are a group of innovative technologies that enable fossil fuels to be used with substantially reduced CO₂ emissions. These CATs can therefore be part of the solution to climate change, whilst still allowing fossil fuel combustion to make a major contribution to security of electricity supply. The Government recognised the potential importance of CATs some years ago and in 2005 produced its strategy for developing CATs for fossil fuels ^[1].

Since the publication of the CAT strategy, the need for action on climate change in order to limit global average temperature rise to 2°C has become more urgent. This is exemplified by the recent advice from the Committee on Climate Change that the UK should start on a steep downward path in greenhouse gas emissions as soon as possible, reaching 80% reduction by 2050. In addition, the need to undertake major replacement of UK power generation plant to meet the requirements of the Large Combustion Plants Directive means that the time-line for the development and deployment of CATs has shortened; there now needs to be more urgent emphasis on commercial demonstration and deployment of CATs, particularly CO₂ capture and storage (CCS).



The 2005 CAT strategy focused on activities that will commence in the period up to 2015, with initial key actions identified out to 2010. Work on technology development and regulatory reform already undertaken as part of the strategy has ensured that the UK is positioned amongst the leading nations in the development and commercialisation of CATs. At the same time, other countries are now moving to meet a 2020 target for commercial deployment of CCS. In order for the UK to meet its needs for replacement generating plant and continue to play a leading role in CCS, the CAT strategy has to be revised and extended.

Most of the objectives of the original 2005 CAT strategy have been achieved culminating in its most significant initiative in 2008, the launch of the UK Competition for a CCS Demonstration Project. This document contains the advice from the Advisory Committee on Carbon Abatement Technologies (ACCAT) for a new strategy that would build on this achievement. It includes recommendations for many additional activities concerning deployment of CCS, which are now needed to ensure large-scale deployment of the full range of these technologies as soon as possible.

VISION

The objective of the CAT strategy is to ensure that the UK takes a leading role in the development and commercialisation of carbon abatement technologies which can make a significant and affordable reduction in CO₂ emissions from fossil fuel use. Delivery of this objective now requires an enhanced focus to encourage deployment as a matter of urgency.

Key elements of the strategy should be:

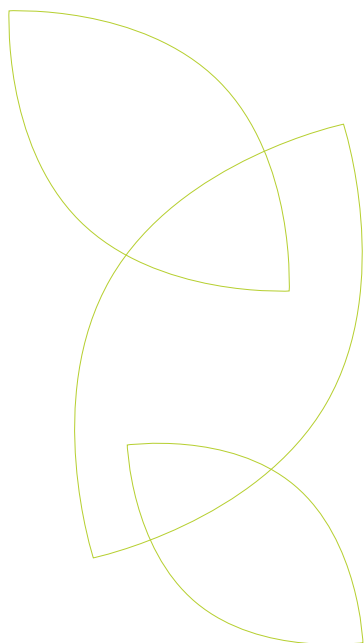
- 1) **Adoption of a target for the successful deployment of CATs, in particular CCS, so that 10% of UK power generation capability (approximately 40 TWh/y) would be provided by fossil-fuel plant operating with CCS by 2020.**
- 2) **Implementing measures to create a capability in CCS in the UK, so that CCS can make a major contribution to the requirement for a 80% CO₂ emission reduction by 2050 (against a 1990 baseline).**
- 3) **Positioning the UK for success in the global markets and influence in the EU and global policy dialogue.**

To achieve this vision requires the creation of a UK CCS industry. This is achievable because the UK has: world leading experts in the key areas, an established engineering and scientific base, a selection of available and known storage sites, an industrial and commercial base that wants this to happen and an urgent domestic need for investment in CCS.

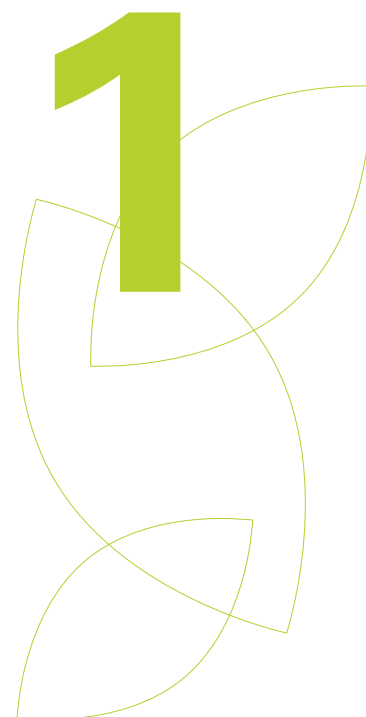
The 10% target, which corresponds approximately to 5 GW of base load fossil fuel plant, is achievable given suitable commercial conditions. For example, in 2007, power plant companies had announced proposals for over 5 GW of fossil-fuel power plant in the UK that would be fitted with CCS if the market conditions were right.

The main focus of this revised strategy is on the demonstration and deployment of CAT technologies. The deployment of CATs, and in particular CCS, is affected by a range of commercial conditions, in particular, financial and regulatory factors. These factors, along with improving public awareness of the opportunities provided by CATs, must also be addressed in order to achieve the new vision.

This document examines the barriers to rapid deployment of CCS and presents suggestions to the UK Government for achieving the strategic objectives consistent with this new vision.



NEED AND URGENCY: THE RATIONALE FOR A REVISED CARBON ABATEMENT TECHNOLOGIES STRATEGY

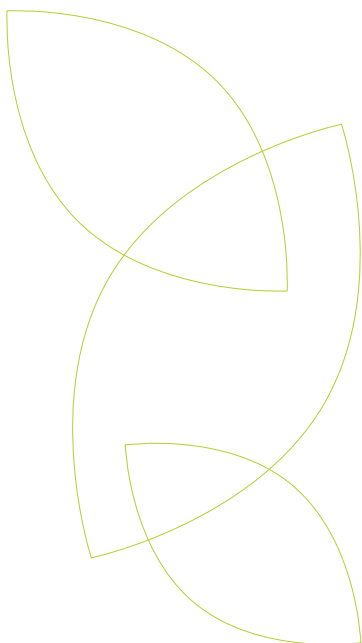


The political imperative to tackle the causes of climate change has become more urgent over the past few years. Extreme weather events and the prospect of economic losses associated with higher global temperatures have focused attention on actions to mitigate the worst effects of global warming sooner rather than later. A consensus has grown around proposals to limit global temperature rise to 2°C, implying a greater than 50% reduction in global GHG emissions by 2050. The Committee on Climate Change in October 2008 proposed that the UK should cut GHG emissions by 80% by 2050 and endorsed the desire to limit average global temperature rise to 2°C. On current trends, energy demand forecasts from international bodies suggest energy use could rise by almost 60% from 2005 to 2030 and by 110% from 2005 to 2050. Commensurate increases in CO₂ emissions are forecast as the share of coal use in the overall energy mix grows – the exact opposite of what is required to limit global warming.

Only strong and concerted action by all the major developed and developing economies can achieve the desired CO₂ reduction outcome by 2050. A combination of energy efficiency measures, demand management, greater use of renewable energy sources, nuclear power, fuel switching to less carbon-intensive fuels, combined with extensive deployment of CCS, can deliver the target reduction in CO₂ emissions. This is supported by multiple high-level studies, including the International Energy Agency 2008 Energy Technology Perspectives, undertaken as part of the G8 Gleneagles programme. While the cost of worldwide CO₂ reduction would be high, it is less than the potential cost of inaction. The cost is lowest if all options are available – CCS can deliver almost one-fifth of the global CO₂ reduction required at a cost of around USD 50/tCO₂ abated, compared with a marginal cost of USD 200/tCO₂ or even as high as USD 500/tCO₂ (IEA 2008) for the most costly options to deliver the required 50% cut in emissions.

Since the UK government published its CAT strategy in 2005, the urgency and extent of the global climate change challenge has become better understood and the political response more clearly expressed by world leaders. CCS has emerged as a key technology that must be adopted swiftly if the political rhetoric is to be transformed into a global reality. In addition to helping meet policy goals on reducing CO₂ emission, CCS deployment in the UK would allow fuel diversity to be maintained in the power sector and so avoid an over-reliance on imported natural gas. More broadly, CCS must be deployed in those developing countries where coal use is growing rapidly and is forecast to continue growing at a rate that would swamp mitigation actions elsewhere. Early deployment in OECD countries is a prerequisite to prove the CCS technologies that developing countries might then deploy under the right circumstances.

The UK has an immediate need for 15 - 20 GWe of new generating capacity to be commissioned by 2015. CCS deployment in the UK would contribute to meeting this need and to CO₂ emission reduction targets.



CURRENT WORLD STATUS OF CAPTURE AND STORAGE OF CO₂



CO₂ CAPTURE

There is a major cost involved in deploying any of the carbon capture technologies. A plant fitted with carbon capture is substantially larger and more complex, less efficient and more expensive to run. There is also a potentially major cost associated with compressing, transporting and storing the CO₂, once captured. The cost of power from a plant fitted with carbon capture is therefore significantly more than that from a plant without capture. CCS technology has not yet been deployed in a full-scale power plant; the readiness of the capture technology varies, which determines whether the particular technology requires research and development, or demonstration, or could be deployed commercially now.

There are three generic process routes for capturing CO₂ from fossil fuel combustion plant:

- Post-combustion capture
- Pre-combustion capture
- Oxy-fuel combustion

Each of these processes involves the separation of CO₂ from a gas stream.

Post-combustion capture technologies have been demonstrated in full-scale gas-fired power plants and in a number of coal-fired pilot plants (0.25 – 1.7 MW); around 10 larger demonstrations, in the range of 5 MW to 233 MW, are under construction and will be in operation by 2009 to 2012. The UK Government competition (for a 300 – 400 MWe plant) would establish the world's largest demonstration of post-combustion capture on a coal-fired plant.

Pre-combustion capture from a synthetic gas produced from coal is already proven at full-scale, and is available today, but this method of capture has not yet been incorporated into an operating power plant. Several major manufacturers offer gas turbines with performance guarantees which can use the resultant decarbonised syngas. The key to successful deployment of pre-combustion capture is to be able to tie these process elements together in such a way as to ensure an efficient yet reliable process. A number of developers do not view this as a significant risk and, as the full CCS chain has also already been demonstrated at commercial scale (3MtCO₂ / yr) for pre-combustion capture, this technology is very close to being available for commercial deployment. Indeed, a number of developers are already consenting large gas CCGT plants that are 'coal conversion ready' and will use this technology once a suitable market framework is in place.

Oxy-fuel has not historically been used for CO₂ capture, but it has been widely deployed in the glass industry for other reasons. Oxy-fuel firing of coal has been demonstrated at ~1MW and is now being demonstrated at 30-40MW.

Pre- and post-combustion and oxyfuel-capture of CO₂ all have the potential to complete demonstration projects and achieve fully commercial deployment by 2020, and in some cases earlier. Whilst deployment readiness varies between the capture technologies, all can be improved with further support and development to reduce further the capital expenditure required and the energy penalty of their use.

It is clear that there is a range of opinions in the world and UK markets as to which capture approach is more appropriate, not least because of differing conditions in those markets (e.g. existing fleet, coal types, water constraints, ambient conditions) that may make a particular approach intrinsically more attractive.

EFFICIENCY IMPROVEMENT

The deployment of CCS, especially post-combustion capture, has long been recognised to be dependent on a base power plant with high efficiency since the additional energy requirements of a capture plant would, otherwise, lead to an unacceptably low efficiency once capture is fitted. Accordingly, the development of high-efficiency power plant is an important step in underpinning the deployment of carbon capture technology. There has been considerable development in the power plant market in recent years with all of the major boiler-makers and steam turbine manufacturers worldwide now offering advanced supercritical designs, and numerous new stations being built with supercritical steam conditions. If such plant were to replace older pulverised fuel power plant then specific CO₂ emissions could be reduced by 20% or more.

BIOMASS COFIRING

Bioenergy is recognised as an important renewable energy source which, when co-fired, can directly replace coal in existing and future plant and thereby reduce fossil carbon emissions. It also offers the potential to further reduce emissions of fossil carbon from plants fitted with CCS.

OTHER INDUSTRIAL SOURCES OF CO₂

The majority of this document concentrates on carbon abatement from power generation, since this sector represents the largest collection of large point sources of CO₂. However, other sectors may also provide significant opportunities for carbon reduction. In particular, in various industries CO₂ is separated from a gas stream as part of an existing process. Although the gas is then vented to atmosphere, such processes provide existing opportunities to capture CO₂ at costs lower than in power generation.

CO₂ STORAGE

Storage in geological formations is a tried and tested technology: there is a long history of storage of natural gas in geological formations stretching back for nearly a century. There is c. 35 years of experience with large-scale CO₂ injection into oil fields for enhanced oil recovery (EOR). There is c. 15 years of experience with small-scale storage of CO₂ / H₂S mixtures in geological formations and over ten years of experience with large-scale storage of CO₂ in a saline formation.

The availability of storage sites for CO₂ is a key determinant of the potential role of CCS in the energy portfolio. Options include storage in active or depleted hydrocarbon fields, storage in brine-filled formations, or possibly storage in unmineable coalbeds.

The UK appears to be well endowed with storage resources, which are predominantly located offshore. Studies by the British Geological Survey, Scottish Centre for Carbon Storage, and others have provided an overview of areas of large storage potential. Estimates have indicated a theoretical storage capacity in excess of 24 billion tonnes (compared to UK emissions from power plant of 170 million tonnes CO₂/yr). Over 60% of this theoretical storage potential lies within brine-filled (saline) formations. Some part of this resource will be required to meet the UK's storage requirements; substantial storage may also be available to receive CO₂ arising in other EU Member States. Some of this hydrocarbon and aquifer storage can be used immediately. However, significant technical investigations must commence soon to better understand the realistic capacity.

CO₂ TRANSPORT

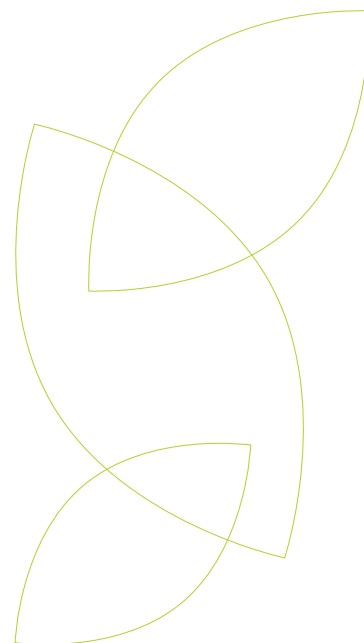
Transport of CO₂ is a proven technology with over 2,500 km of pipelines moving over 20 million tonnes/year through large diameter pipelines primarily in the Permian Basin area of the US.

This pipeline network (feeding into Texas) is a version of the type of hub and spoke arrangement that is expected to be required for a CCS network in the UK. Multiple sources of CO₂ (primarily from large natural reservoirs of CO₂) feed into long distance pipelines transporting pressurised liquefied CO₂, before branching to feed over fifty customers for the CO₂.

Marine shipping of CO₂ is technically feasible and is already practiced at small-scale for the food industry. This is achieved with CO₂ under pressure in the liquid phase. The use of ships may be an option for small quantities of CO₂ in the early stages of deployment of CCS.

Experience from the US has shown CO₂ pipelines to be safe and reliable. The most significant, but still very low, risks relate to accidental damage from third parties. Safety is generally addressed using modelling to define the size of the zone around the pipeline needed to ensure dilution and dispersion of CO₂ and contaminants to a safe level. Block valves that operate on loss of pressure may be used to minimise the volume of CO₂ that can be released.

A number of studies have been, and are being, performed looking at the shape of future CO₂ hubs in the UK. This will be an important area for the commercial deployment of CCS. Although separate hubs may be initially constructed, common standards are needed to define the quality of CO₂ entering a network as this has implications for the design, operation and integrity of the complete pipeline system. Standardised CO₂ quality will also facilitate the linking of separate hubs at a later stage as CCS penetration increases over time. Additional work may be required to consider potential safety issues in the UK situation, given the higher population density in the vicinity of likely pipeline routes compared with the Permian Basin. The design and development of a CO₂ collection pipe network onshore, and a CO₂ distribution network offshore, is a major infrastructure development, and work is needed to ascertain if this will be produced by a market response, or if this will (more probably) require Government intervention.





GLOBAL INITIATIVES

Interest in CATs, especially CCS, is increasing rapidly worldwide. This is accompanied by increased activity on practical projects, including full-scale implementation of the technologies.

In June 2008, the G8 energy ministers, meeting in Hokkaido Japan, gave strong support to the need for 20 large-scale CCS demonstration projects by 2010, with a view to beginning broad deployment of CCS by 2020.

The European Commission's Strategic Review of Energy Policy includes promotion of Sustainable Fossil Fuels and support for the implementation of CCS as part of the EU objective to reduce emissions by 20% on 1990 levels by 2020. In December 2008, the EP agreed a package of proposals on climate change and energy, including directive on the geological storage of carbon dioxide and directive amending Directive 2003/87/EC on greenhouse gas emission allowance trading under Phase III of the EU Emissions Trading Scheme. These Directives include a number of important developments for CCS:

- Commitment to a 20% reduction of greenhouse gas emissions from 1990 levels, rising to 30% if a global deal is reached;
- The centrally set cap on the EU Emissions Trading System (EU ETS) will deliver emissions 21% below 2005 levels by 2020;
- At least 60% of EU ETS allowances to be auctioned by 2020. In Phase II only around 3% of allowances are to be being auctioned;
- Recognition of CO₂ stored in accordance with the Directive on geological storage of carbon dioxide as abated within Phase III of the EU ETS;

- Use of up to 300 million EU ETS allowances, worth billions of pounds, to part-fund CCS demonstrations of a range of technologies in different geographic locations;
- A risk management framework for regulating the environmentally safe storage of CO₂, including provisions enabling the long-term responsibility for storage sites to be handed over to national competent authorities;
- A requirement that new plants with an electrical output of 300 MW or more have sufficient space for CO₂ capture and compression equipment, providing that it is technically and economically feasible to retrofit capture and transport CO₂ to a suitable storage site, alongside a review in 2015 to examine whether it is necessary and practicable to establish an emissions performance standard for new power plants.

In Europe there are a large number of projects under development, covering all three capture technologies and a range of storage sites (onshore and offshore). Norway has most experience of CCS in practice with two offshore projects operating and two onshore projects in advanced evaluation, including Mongstad where the EU has agreed 80% State Aid. Small-scale projects are also operating in Germany and Denmark, and soon in France. Several large projects are planned around Rotterdam, with an offshore pipeline in 2012. This could become a CO₂ hub for the EU.

In Australia, support for CATs is increasing from federal and state governments. Following an initial programme of mapping the nation's CO₂ storage capacity, several pre-commercial and commercial-scale CCS projects are now being constructed. The federal government has also created the Global Carbon Capture and Storage Institute (GCCSI), with an annual budget of AUS \$ 100M, to enhance global co-operation and co-ordination in the delivery of CCS Demonstration plants.

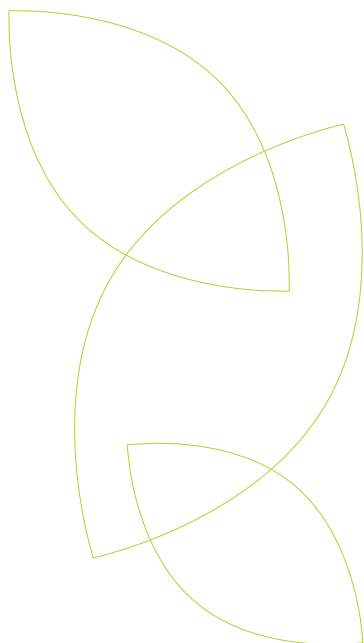
In Japan, no full-size CCS projects have yet been proposed. In 2007, the Environment Ministry announced legislation on sub-sea storage in aquifers as a framework for implementing commercial storage projects. Underground storage capacity in Japan has been estimated at 150 Gt of CO₂. METI has announced plans to establish CCS facilities in Japan and abroad, with the aim of reducing industrial emissions by 200 million t/y, half of which will be in Japan.

In USA, substantial investment by the US Department of Energy (DOE) is establishing a major national capability in CATs, and especially CCS. The programme relies on public-private joint ventures in R,D&D, covering a wide range of technologies. DOE has recently announced \$390M in co-funding for the first 6 storage projects under the Regional Carbon Sequestration Partnerships, most of which will inject more than one million tonnes of CO₂, mainly from low-cost sources. The Energy Improvement and Extension Act of 2008, which was passed at the same time as the emergency measures to deal with the problems in the financial system, includes a new CO₂ sequestration credit of \$20/ton for secure geological storage and \$10/ton for CO₂ captured in EOR or in natural gas recovery projects.

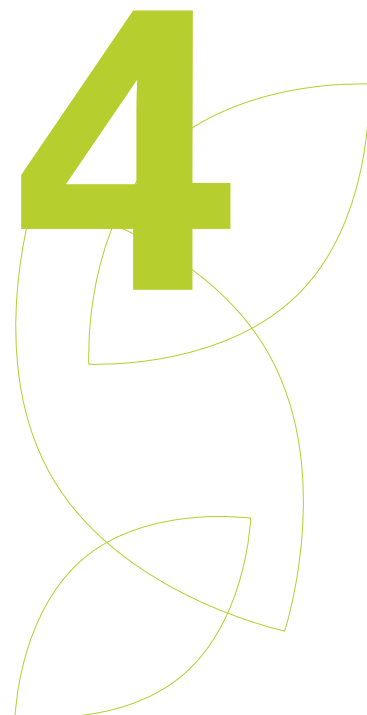
Canadian policy towards CATs is rapidly evolving. The flagship of Canadian work on CCS has been the Weyburn/Midale project, which has been operating EOR since 2000 using CO₂ from the gasification of coal at Beulah, USA. Phase 2 of an international monitoring project recently started. Other commercial CO₂-EOR projects have been announced in Canada using captured CO₂. A post-combustion capture pilot plant has been in operation for some years on a side-stream from a coal-fired power plant in Saskatchewan. Alberta has announced a CAN \$ 2 billion fund to support CCS on coal and tar sand operations, as well as a pipeline network design.

Many other nations are now proceeding with their first CCS projects, with R&D aimed at plugging gaps in knowledge, especially in respect of storage, and exploring the opportunities for improved, second generation technologies. These include: Brazil, China, India, South Africa and Abu Dhabi.

It is important that CCS should become acceptable for funding under the Clean Development Mechanism (CDM) or any subsequent scheme that would facilitate transfer of the technology to developing countries. This will provide opportunities for UK investors to engage in low-cost CCS projects in particular, such as those using concentrated sources of CO₂.



STATUS OF CAT-RELATED INDUSTRIES IN THE UK



Most CAT developments will be focused on the power generation sector though other sectors should also have a strong interest in their development, including fuel suppliers, other operators of plants emitting large quantities of CO₂ (cement works, steel works, petrochemical plants, etc.), the process industries, pipeline contractors, the offshore industry as well as legal and financial services – and their supply chains.

Industry in the UK, including companies which have a long involvement in the supply of power plants as OEMs/EPC contractors, are involved at every level in CATs, including CCS, both in the UK and also, through their associated companies and export businesses, overseas. Almost all of the UK industry with an interest in CATs is “globalised” - either part of a larger global group or having subsidiaries/associates overseas. Globalisation brings access to competitive sources of materials, equipment and manufacturing and also brings access to new markets that would otherwise be closed. The combination of the global reach of UK companies, the installed base from previous export business combined with strong R&D, is an excellent platform from which to build up UK CATs industries and to roll out CATs to the global market. The international reach of UK companies also provides these companies with access to R&D, demonstration and technology from other parts of their groups overseas.

Value to the UK will come from exploiting the know-how to develop, design and implement superior CAT systems that match the needs of both the UK and export markets. Most OEMs own their technology and intellectual property (or have long-term licences for it). They can support their proposals with references and can give guarantees based on their understanding of the technology and their experience. Ownership of technology is a basis for sustainable business growth.

UK industry - supported by the universities and other agencies - has a broad and extensive involvement in CATs and is well-positioned to support government objectives, both to help the deployment of CATs globally and to develop major business and employment in this field.



OPPORTUNITIES AND CONSTRAINTS FOR THE UK

OPPORTUNITIES FOR ESTABLISHED BUSINESSES

Currently there is no government policy specifying how much coal and how much gas-fired plant would constitute an appropriate basis for planning. Based on work carried out by the Coal Forum, it is, however, likely that there will be a requirement for a large amount of fossil-fired plant to be built in the UK.

The global market for new and replacement thermal power plants is currently about 140 GW p.a. (90 GW p.a. of new capacity and 50 GW of replacement capacity, assuming a replacement rate of 2%). The IEA, in looking at future scenarios, projects that a large part of this thermal plant build will be fitted with CCS. Looking out to 2030, the IEA “450 stabilisation” case^[2], suggests that 310 GW of coal-fired and 170 GW of gas-fired plant will be fitted with CCS by 2030. This would imply an average construction of c.40 GW p.a. between 2020 and 2030. The IEA has extended this case out to 2050^[3] in a “Blue Scenario” in response to the G8 and EU targets of reducing emissions by 50% from current levels by 2050. Under this scenario, 700 GW of coal-fired plant and 817 GW of gas-fired plant would be equipped with CCS by 2050.

Scenario analysis by the IEA indicates that CCS would mainly be used in industrialised countries, although by 2050 use of CCS in developing countries may reach comparable levels. Countries such as China and India already recognise the need for highest efficiency and are interested in understanding the potential for CCS against possible limits posed by local geology.

Based on the above projections of CCS installations the potential world market would be £100Bn per year. At a 10% market share this could be worth £10Bn per year to the UK.

OPPORTUNITIES FOR NEW BUSINESSES

So far, this section has concentrated on the established industries that could be involved in CATs. However, there is also the possibility of new production and service companies being established based on the know-how developed in the R,D&D and deployment programme. Opportunities also exist for the longer-term deployment of CCS technologies where there is considerable potential for innovation. For example, there are requirements for new membranes, chemical absorbers and catalysts to reduce the cost and increase the efficiency of capture plant. Similarly, there is a need for more accurate and lower-cost methods for developing CO₂ injection at geological storage sites and for monitoring their performance for decades during and after injection.

Knowledge of CO₂ storage resources is inadequate almost everywhere in the world. UK has relevant skills and knowledge in offshore engineering and in mapping and monitoring underground storage of CO₂. There are opportunities for the UK here but this will require training more people and enabling them to gain the necessary practical experience and skills through work on real projects.

The UK is particularly strong in the provision of a broad range of support services and CATs will present another major market for these. In addition to the financial services needed for their implementation, CATs will require auditing and verification systems to confirm the delivered reductions in CO₂ emissions and to register and trade these reductions in the growing emissions trading market. There will also be a demand for know-how to evaluate and minimise the overall environmental impacts of CATs, together with how to frame and implement regulatory regimes to control their operation.

The UK has a strong research base in universities and other agencies in fossil fuel combustion, membranes and catalysts, and in subsurface development, monitoring and offshore engineering - although at present little of this work is directed at CATs. This expertise could form the basis of new spin-off companies.

CONSTRAINTS

The aim is to introduce and commercially deploy CCS in the UK as soon as possible. The key determinants of the rate of commercial deployment are:

- a) technology readiness;
- b) a financial and market framework that ensures that projects receive appropriate risk-adjusted returns;
- c) the regulatory environment;
- d) the development timescale for projects and the link to the process of “learning by doing”;
- e) a national onshore and offshore transport network, to minimise add-on costs for newer projects;
- f) capacity and skills of the industry to build first the demonstration projects and then subsequent commercial projects.

Technology Readiness

For the three main approaches to CO₂ capture described above:

- Pre-combustion capture can be deployed today, giving large-scale operating plant by 2015 – issues are risks and costs associated with operational integration and “first-of-a-kind” (FOAK) application.
- Post-combustion capture is being deployed today at small-scale in both the USA and Europe, giving the potential for large-scale plant operating by 2015 – issues are scale-up from pilot to full-size, operational integration and “first-of-a-kind” risk.
- Oxyfuel is now starting demonstration in pilot plant so there is potential for full-scale plant to be operating by 2018 – issues are scale-up and first-of-a-kind risk.
- Pipelines for the transport of CO₂ are currently operating onshore; application of suitable pipeline networks, especially offshore, could be undertaken by 2015.
- Storage of CO₂ will require characterisation with both established and innovative technology and regulatory approval for use, so that first applications in the UK could happen within 5-8 years from now.

However, early deployment is associated with very considerable FOAK risks.

Financial and Market Framework

Carbon is now valued and traded in the EU Emissions Trading Scheme. In the long term, the hope is that carbon prices will be sufficient to drive investment in CCS for both coal- and gas-fired generation and for other carbon intensive processes. The current EU proposal will encourage this by mandating full auctioning of allowances from 2013 in the power sector, progressively reducing the use of free allowances in other industrial plant (phasing them out by 2020) and by setting a long-term reducing emissions cap. However, it is far from clear whether this will indeed result in the market choosing to invest in CCS and if so when, given that additional established subsidies are available to renewables, both providing an alternative investment opportunity and potentially depressing carbon market prices. To justify CCS investments even with no FOAK risks requires the carbon price in the Emissions Trading Scheme to be sufficiently high or some other incentive to be applied.

The legally binding targets of the Climate Change Committee can be met most cost-effectively with CCS as a large part of the UK energy mix. Government actions, in the UK and worldwide, have not yet been of a size or volume commensurate with this challenge. To demonstrate new technologies in a competitive market requires subsidy to reduce risk for pioneering companies. It is clear that neither the normal EU-ETS, nor the special allowances voted by the EP will provide this subsidy. Additional UK funds are required for the first CCS projects up until 2020. Established subsidies are available to new renewable technologies, these provide an alternative investment opportunity to CCS, and so distort and depress the carbon market price. A subsidy is needed if CCS is to develop in the UK, in addition to any EU special allowances.

The Regulatory Environment

Whilst the regulatory framework to allow final investment decisions on CCS projects is not yet in place, the UK Government has made extremely good progress.

The key areas are:

- The legal framework which allows offshore storage.
- A licensing process for CO₂ storage volumes.
- The arrangements for transfer of long-term liability for stored CO₂ to government.
- The recognition that stored CO₂ does not require surrender of emission allowances under the EU ETS.

The EU CCS Directive that is currently being finalised for approval by the European Parliament in Spring 2009 provides the supporting legislation that ensures that stored CO₂ is recognised within the Emissions Trading Scheme and hence emission allowances need not be surrendered for the CO₂ abated and stored by CCS.

Deployment Timescale

The time from project conception to operation of the station is typically envisaged at 5-6 years - the exact arrangements vary with project and the developer involved. This process applies separately to both the power station and CO₂ transport and storage investment although the time required for gaining approval for storage sites and permission to construct pipelines could well take 5-8 years, which may be longer than the steps for building the power station.

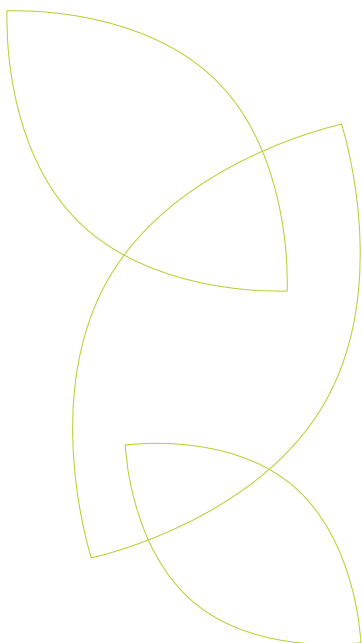
Transport Network

It is clear that large storage volumes do not exist onshore directly beneath UK power plant. Therefore, CO₂ will need to be transported to larger storage beneath the North Sea. Both the UK and Norway have globally significant storage volumes. However, these sites need to be accessed from the UK and from the EU. Building long pipes for individual projects is more costly than shared facilities. It is unclear how private developers can be provided with a vision of CO₂ volumes in prospect to attract investment in oversize pipes or networks. Government guidance or direct intervention may be needed.

Industry Capacity and Skills

The CAT-related industries in the UK - described above - are operating at full capacity (2008) due to rapid growth in their markets over the last few years, combined with the loss of experience as retirements among professional engineers exceed recruitments.

Skills shortages are summarised in a BERR/DIUS report, which is about to be published. Industry, working with government has begun to respond, for example, by the E.ON/EPSC Strategic Partnership, the EPSC call for proposals for doctorate training centres, the new modular MSc in Power Plant Engineering at the University of Strathclyde and the MSc in CCS at the University of Edinburgh.



DEMONSTRATION AND DEPLOYMENT OF CATS IN THE UK

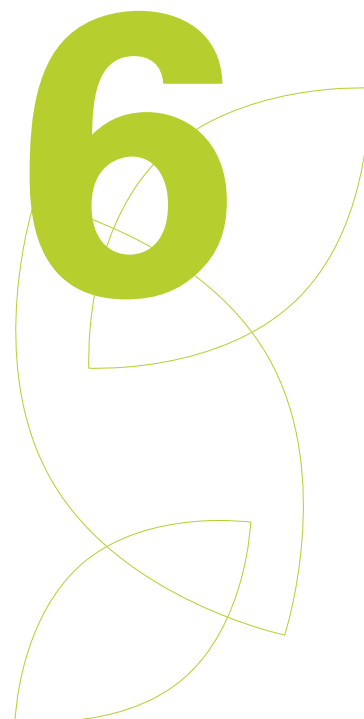
TIMETABLE AND AMBITIONS

Full-scale demonstration and deployment will be dependent on a number of factors. Project developers and other stakeholders will need to be satisfied that any CCS plant will be safe, effective, environmentally benign, reliable and offer a return on investment.

To meet these requirements, various stakeholders need to make different contributions. Equipment suppliers need to advance the understanding of the technologies through fundamental, pilot and design studies and develop technologies for which they will offer guarantees. Technology buyers such as utilities will need to become sufficiently familiar with technology options to allow them to be informed buyers of technology and to judge competitor technologies offered to the market and to assess the impact that the technology will have on plant operation.

Operators, planning authorities, regulators, the general public and other stakeholders such as NGOs need to be confident that installations will be safe and environmentally benign, which will require engagement from all of those groups, in addition to equipment suppliers and utilities. Further, Government will need to provide the necessary guidance to planning authorities of the necessity for CCS plant and infrastructure.

In order to meet the projected market requirements, technology demonstration, supported by continuing R&D, and the build-up of capacity are needed on the scale and timeline illustrated in the table below.



CCS Demonstration - timescales and ambitions

Research and Development	Now and continuing
UK Regulations	2010, with adaptation to 2025
Early demonstration projects (including capture-ready plant)	2012/15
UK Competition 300 MW CCS demonstration on pulverised coal	Operational by 2014
Phase 3 of ETS	From 2013
10-12 demonstrations in Europe	Operational by 2015
EU target for full commercialisation	By 2020
World CCS requirement to 2030 based on IEA data ^[2] , "450 stabilisation" case	22 coal (800 MW) CCS and 20 gas (500 MW) CCS power plants per year from 2013 to 2030 ¹
World CCS requirement to 2050 based on IEA data ^[3] , "BLUE Map" scenario	28 coal (800 MW) CCS and 52 gas (500 MW) CCS power plants per year from 2020 to 2050 ²

Groups such as investors and insurers will need to be sufficiently informed of the technologies to view them as secure investments. Partly, this will be done by establishing a track record of technology performance, which the proposed programme will provide, but it will be essential to have significant public funding to defray the risk until the technology is proven. Thus, it will be essential to have some form of financial guarantee for early deployment projects. In the longer term, once the technology is established, a market could be supported by the ETS which could drive a competitive market, promote innovation and also drive significant long-term investment in CCS technologies, provided that the market was operated in such a way as to underpin a sufficiently high long-term price for carbon.

Given a transition market structure that allows investment in CCS in the UK, it is entirely credible to aspire to have at least 5 GWe from coal CCS operating by 2020. This would generate 40TWh p.a. representing 10% of annual generation and storing around 30MtCO₂ pa that would otherwise be released if unabated coal plant were to be built.

1 An average of 22 x 800 MW coal-fired power plants with CCS each year from 2013 to 2030 equates to 300 GW in total, while 20 x 500 MW gas-fired plants with CCS equates to 170 GW in total. It was assumed that 12 or more coal-fired CCS demonstration plants would be built prior to 2013 (with a total capacity of 10 GW) to give a total of 310 GW by 2030. The rate of CCS plant construction would grow significantly after 2020 to 40 GW per year or more.

2 An average of 28 x 800 MW (new and retrofit) coal-fired plants with CCS each year from 2020 to 2050 equates to 672 GW in total, while 52 x 500 MW (new) gas-fired plants with CCS equates to 780 GW in total. It is assumed that 28 GW of coal-fired plants and 37 GW of gas-fired plants are built before 2020 to give totals of 700 GW and 817 GW respectively.

The benefits to the UK of accelerating CCS deployment in this way are very large:

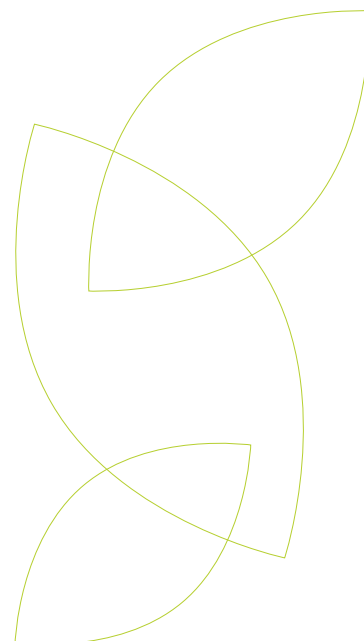
- Minimise the growing dependence on imported gas with minimal impact on the environment by facilitating a tranche of new coal-fired stations with CCS.
- Create a multi-faceted CCS industry based on several different CCS technologies in the UK which is able to secure business internationally in what is likely to be a multi-billion pound industry.
- Make it more certain that the UK will reach its carbon reduction targets, demonstrably meeting its share of worldwide carbon reduction and achieving this in a cost-effective way.
- It might be possible to enhance oil recovery from UK fields using CO₂.

To achieve these benefits, it will be necessary to build up industry capacity and this will require a progressive increase in the number of projects. If the IEA “BLUE Map” scenario is taken as a basis, this will require an industry capacity to be built for CO₂ capture and storage comparable in size to the power plant industry. Globally, the industry must move from delivering 10-12 projects in Europe over seven years to 80 units per year from 2020 onwards.

STAKEHOLDER PERCEPTIONS OF CCS IN THE UK

Stakeholder acceptance of CCS remains a key unknown for the large-scale deployment of CCS. A better understanding of stakeholder concerns leading to an enhanced dialogue is central to moving forward in this area. To promote the engagement process, further work would be beneficial in the following areas:

1. Better knowledge of stakeholder opinion in the UK, which includes a need for improved knowledge of non-expert stakeholder and public opinion regarding CCS.
2. A properly planned and funded public communications and engagement strategy.





CAT STRATEGY AND ACTIONS

The preceding sections explain why the UK CAT strategy must be updated and the issues that must be addressed if the overall objective and vision proposed in section 1 are to be achieved. The main messages from the preceding sections can be grouped into eight key areas, each of which needs action from government and industry to achieve the vision: demonstration of CCS; financial incentives; planning and regulatory frameworks; science and technology R&D; CO₂ storage; transport infrastructure; capacity building; and public outreach and education.

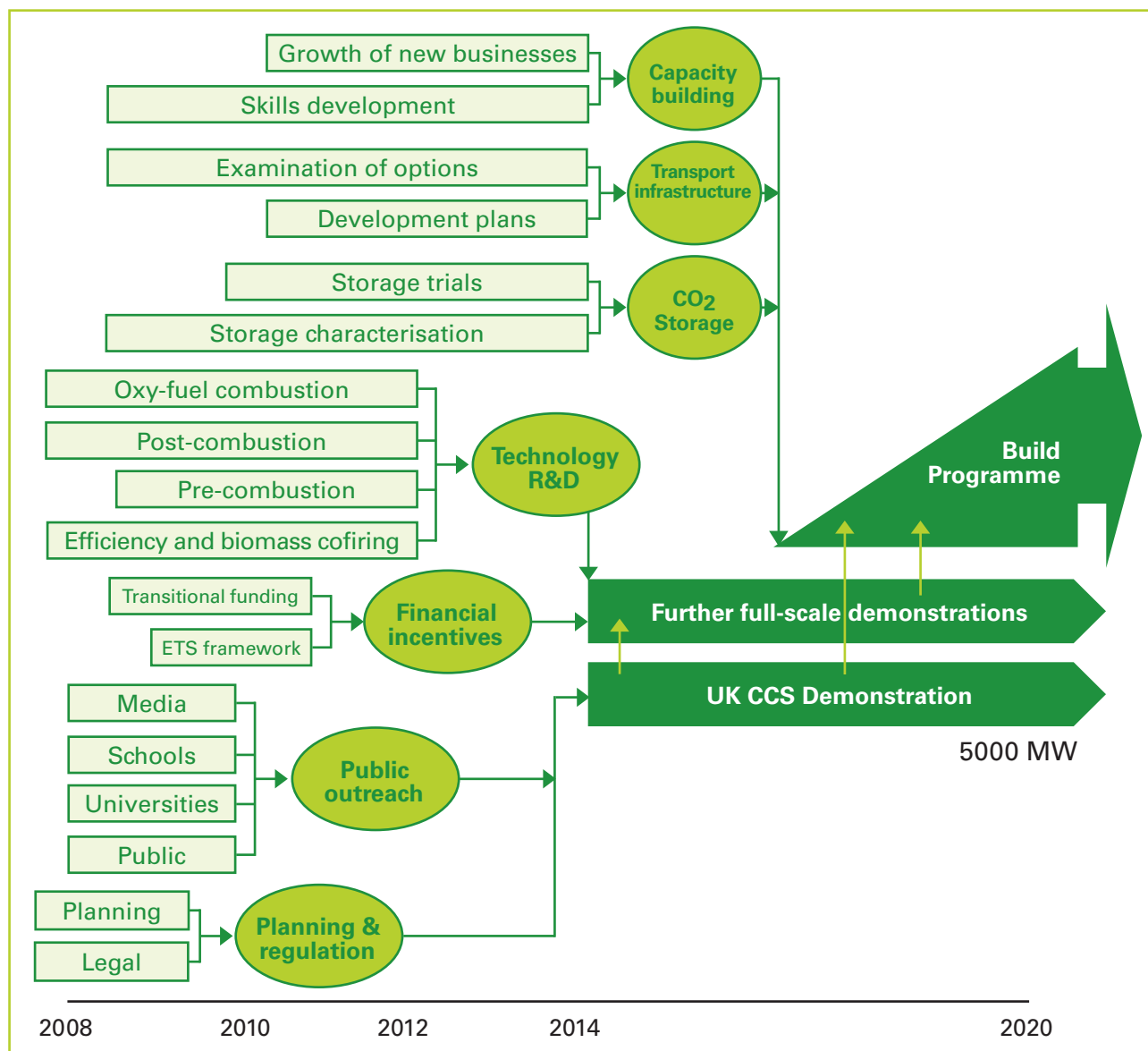
These key areas and the challenges within them need to be addressed in a managed way, with key milestones as illustrated in the Route Map figure (below). The early demonstration projects need to be operational by 2012/15 and this should lead into these being part of the 10-12 demonstrations being called for in the EU by 2015.

The demonstrations in the UK should include:

- 1) A number of full-scale demonstrations of CCS, including coal, gas and low-cost industrial sources of CO₂.**
- 2) Multiple storage demonstrations in the UK, including EOR (if achievable), depleted gas and oil fields and particularly saline formations.**
- 3) Early stages of a number of separate CO₂ transport networks linking one or more storage sites and several capture sites.**

The timescales for each activity and each key area have been chosen to ensure that the vision of “10% of UK power generation (approximately 40 TWh/y) would be provided by fossil-fuel plant fitted with CCS” can be achieved by 2020.

CAT strategy: Route Map illustrating key milestones



Taking account of the above, a portfolio of government-supported actions involving industry is needed to address the following:

1. Demonstration Projects

Government support is needed for a series of demonstrations of CCS technologies by UK companies, including one or more full-scale demonstrations of the complete CCS train in the UK by 2014. Three coal and one gas large-scale CCS demonstration projects should be operational by 2015 (in-line with an equitable UK share of EU, G8 and IEA objectives). Government should not seek to pick technology winners, rather the market should be

allowed to decide. However, it is likely that different technologies will have different applications and the Government should encourage at the least both pre- and post-combustion capture technology and storage in an aquifer and a hydrocarbon field.

The government should also support participation by UK companies in overseas projects where these provide opportunity for UK organisations to gain practical experience of CCS in a cost-effective manner. The government should liaise with overseas governments to facilitate such participation.

2. CO₂ Transport Infrastructure

Examine the regional and national options for development of the CO₂ transportation infrastructure necessary to achieve the lowest-cost network for full-scale deployment of CCS recognising the need to build on private sector investment initiatives. Assess the extent to which optimum combinations of CO₂ sources and stores can be identified in advance of implementation.

Develop plans for large-scale deployment of transport infrastructure, including recognition of likely obstacles, such as financing and permits; identify options for overcoming these barriers.

3. CO₂ Storage

Support the demonstration of storage through a series of specific surveys followed by practical injections covering the range of cost-effective storage options relevant to UK users at both research scale and pilot scale. Incorporate monitoring in these projects in order to build experience and verify sub-surface models. A national test centre for offshore subsea monitoring may be needed.

Support more detailed characterisation of cost-effective storage options relevant to UK users in particular recognising the large potential of saline formation storage available to UK CCS projects.

4. Incentives for Demonstrations and Early Stage Deployment

Promote deployment of full-scale CCS projects that can contribute to UK carbon reduction targets.

Work with developers to secure appropriate UK share of EU support for demonstration projects.

Provide supplementary funds to build on CCS demonstration projects which secure support from the EU to produce networks and further capture projects.

Consequently, the Government must urgently establish incentives for deployment of a tranche of “early stage deployment” projects, additional to the initial full-scale demonstrations (the “Build Programme” indicated in the Route Map above). Such incentives should supplement the incentive of the carbon price, until this provides sufficient incentive itself. The scheme should be announced by the end of 2009 so that these projects would be developed and committed as soon as possible.

5. Support for R,D&D

Develop the capabilities - including test rigs and underpinning sciences - that will support deployment and also underpin the training of a new generation of engineers and scientists.

Build upon existing and foster new agreements to promote and accelerate international activities on CCS technology R,D&D, including gaining access to overseas opportunities.

6. Public and Stakeholder Awareness

Promote understanding of CATs and engage the full range of stakeholders. The UK Government should:

1. Facilitate the development of a better understanding of stakeholder opinion in the UK, in particular secondary and tertiary stakeholders through commissioned surveys.
2. Develop a properly planned and funded communications and engagement strategy.

7. Regulation

Work with national and international bodies to develop long-term, stable regulatory and financial frameworks to enable the global deployment of CCS.

8. Skills and Capacity

Address how to build up the capacity of the CAT industries in the UK, how to find the skilled researchers, professional engineers, technicians and skilled craftsmen and how to maximise the employment opportunities which will arise out of investments in CCS in the UK and abroad.

In addition to these eight key areas there are two 'cross-cutting' areas:

9. International Outreach

Continue to play a leading role both with the European Commission and with other multi-state initiatives in the demonstration and deployment of CCS.

Promote UK-based technology abroad and support technology and knowledge transfer, especially in developing countries.

Provide assistance to developing countries to help identify their potential storage capacity.

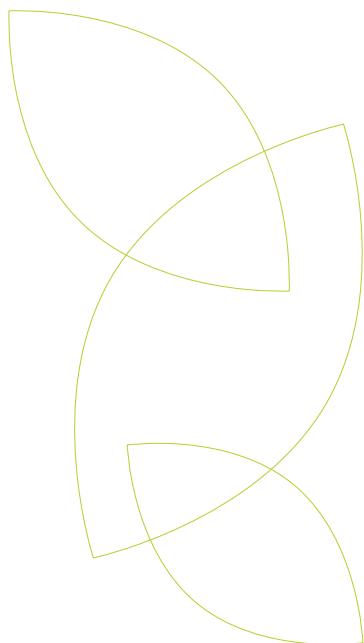
Stimulate rapid deployment of CCS worldwide through technology transfer, particularly in countries which have a heavy investment in pulverised coal power plant and which plan to add further substantial coal generation.

Seek to position UK industry to take full advantage of the future global market for CATs.

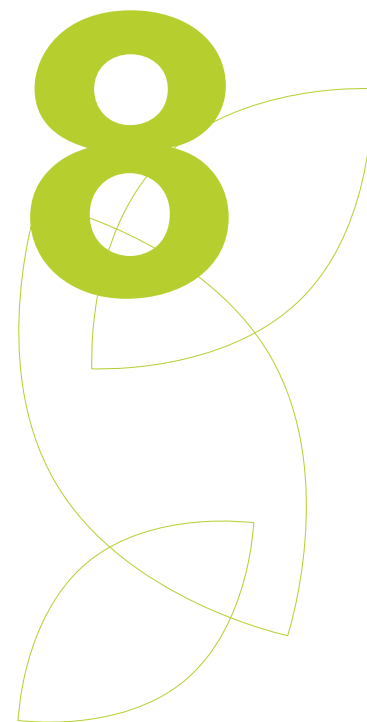
Promote the UK's strength in the broad range of support services for CATs and to encourage developments that could form the basis of new spin-off companies.

10. Establish a Managed Programme to co-ordinate R,D&D activities across the wide range of activities in which it is engaged.

Some, although not all, of the industries involved in CATs are well-established, but risks and uncertainties are considerable, particularly for CCS. Therefore, a Government-supported CATs programme is needed with appropriate funding to stimulate investment by industry, and to support academic research, for future development and deployment. This programme would benefit from being a managed programme across all the relevant government departments and funding agencies linked by the overall objective of this strategy and driving towards and beyond widespread roll-out of CCS by 2020. The activities of the Research Councils, Technology Strategy Board, Carbon Trust, Energy Technologies Institute, Environmental Transformation Fund and the Government Demonstration Programme have to be joined up in a more coherent programme. It is vital that each strand of technology (pre, post, oxy, transport, storage) will be taken forward and that there are no gaps.



CONCLUSIONS AND RECOMMENDATIONS



This strategy document has been prepared by the Advisory Committee on Carbon Abatement Technologies as advice to Government on the future development of CATs. The strategy sets out a framework that is designed to ensure that Government's own objective, of ensuring that the UK takes a leading role in the development and commercialisation of CATs, can be achieved.

In order to achieve this objective, there must now be more focus on deployment and this must be done with an increased urgency.

ACCAT believes it is essential that this strategy be adopted by Government in order to achieve these targets and to retain its position amongst the leading nations.

There are major opportunities for established UK businesses as well as opportunities for new businesses. One estimate from the IEA is that global power generation capacity with CCS will require a power-sector investment of USD 1.5 trillion through to 2030 and the UK should be aiming to win a significant part of that business. Past performance in the power sector suggests that £10Bn/yr should be possible for the UK. However, there are barriers and constraints both national and global, to be overcome; in particular, the key determinants of the rate of commercial deployment of CCS are:

- a) technology readiness;
- b) a financial and market framework that ensures that projects receive appropriate risk-adjusted returns;
- c) the regulatory environment;
- d) the development timescale for projects and the link to the process of "learning by doing";
- e) the capacity of the industry.

The strategy addresses each of these.

The strategy proposes a set of ambitions and a route map extending out past 2020, which include a set of eight action areas covering: demonstration of CCS; financial incentives; planning and regulatory frameworks; science and technology R&D; CO₂ storage; transport infrastructure; capacity building; and public outreach and education. International outreach and collaboration will be key for many of the action areas.

This strategy would benefit from being a managed programme across all the relevant Government departments and funding agencies linked by the overall objective of this strategy and driving towards widespread roll-out of CCS by 2020.

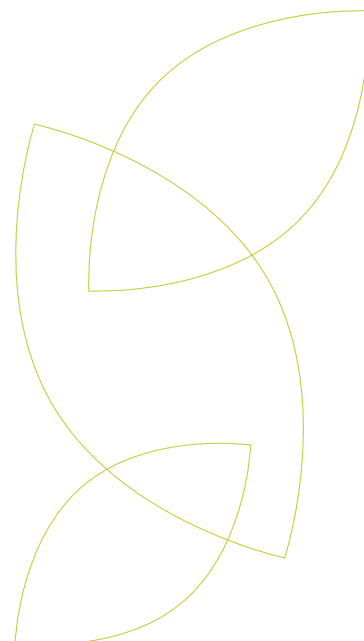
RECOMMENDATIONS

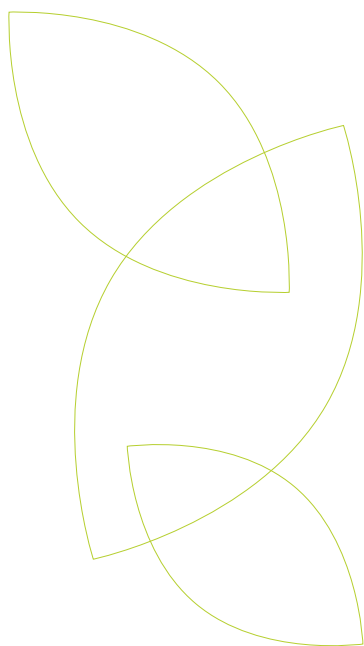
1. The revised CAT strategy sets some challenging targets:
 - **Adoption of a target for the successful deployment of CATs, in particular CCS, so that 10% of UK power generation capability (approximately 40 TWh/y) would be provided by fossil-fuel plant operating with CCS by 2020.**
 - **Implementing measures to create a capability in CCS in the UK, so that CCS can make a major contribution to the requirement for a 80% CO₂ emission reduction by 2050 (against a 1990 baseline)**
 - **Positioning the UK for success in the global markets and influence in the EU and global policy dialogue.**

ACCAT recommends that the Government accepts these targets in order to help the UK achieve its own objectives.

2. ACCAT recommends that this strategy be adopted by Government in order to achieve these targets and to retain its position amongst the leading nations. The following key elements of this strategy need to be pursued urgently:
 - The UK should be hosting three coal and one gas full-scale CCS demonstration projects, to be operational by 2015. A range of geological storage settings should also be tested by these projects, including 2 or 3 different types of saline aquifer, a depleted gas field, and a depleted hydrocarbon field (with or without enhanced oil recovery).

- Plans must be developed for large-scale deployment of transport infrastructure, including recognition of likely obstacles, such as financing and permits; identify options for overcoming these barriers.
 - The Government must urgently establish incentives for deployment of a tranche of “early stage deployment” projects additional to the initial full-scale demonstrations. Such incentives should supplement the incentive of the carbon price, until this provides sufficient incentive itself.
 - The Government and industry must work with national and international bodies to develop long-term, stable regulatory and financial frameworks to enable the global deployment of CCS.
 - A sustained programme of R,D&D support for universities and industry is needed to provide underpinning support to the demonstration programme and to perform strategic research at a level competitive with rival and partner nations in the EU and world.
 - A strategic programme of competencies and skills development is required, to develop researchers, professional engineers, technicians and skilled craftsmen.
 - The Government and industry must promote understanding of CATs, particularly CCS and engage the full range of stakeholders including the public.
- 3) A managed programme is required to co-ordinate the UK’s research, development and demonstration activities in CCS. This should include international outreach activities, particularly to promote UK-based technology abroad and support technology and knowledge transfer, especially in developing countries.
- 4) The Government and industry need to rise to the scale of the CCS challenge and they need to do this now.





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