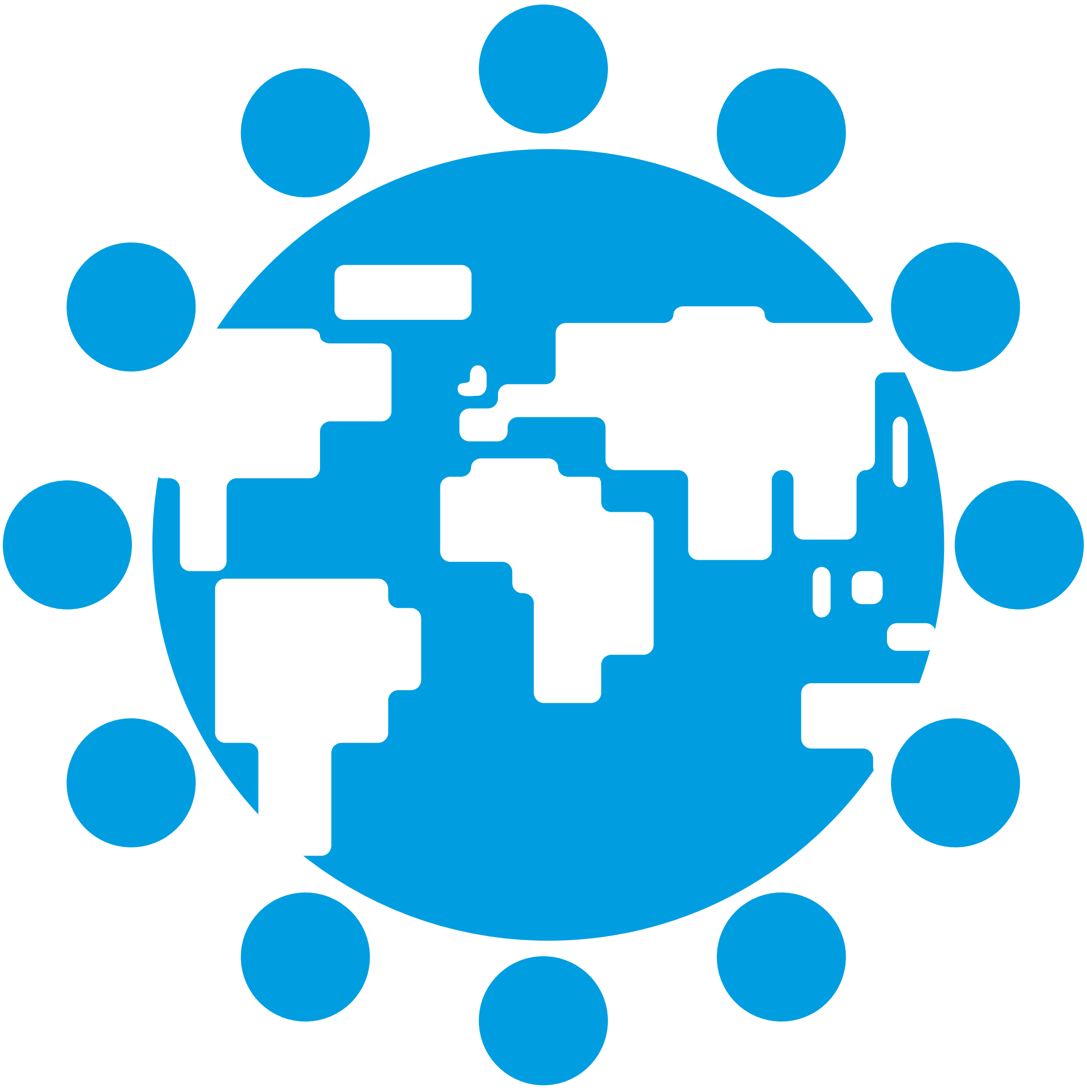

Carbon Capture and Storage

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THE °CLIMATE GROUP

Breaking the Climate Deadlock
Briefing Paper

About the 'Breaking the Climate Deadlock' Initiative

'Breaking the Climate Deadlock' is an initiative of former UK Prime Minister Tony Blair and independent not-for-profit organisation, The Climate Group. Its objective is to build decisive political support for a post-2012 international climate change agreement in the lead up to the 2009 UN Climate Change Conference in Copenhagen. Its particular focus is on the political and business leaders from the world's largest economies, particularly the G8 and the major developing countries. The initiative builds on Mr Blair's international leadership and advocacy of climate change action while in office, and The Climate Group's expertise in building climate action programmes amongst business and political communities.

This briefing paper and its companions were commissioned by the Office of Tony Blair and The Climate Group to support the first Breaking the Climate Deadlock Report – 'A Global Deal for Our Low Carbon Future' – launched in Tokyo on June 27th 2008. Written by renowned international experts and widely reviewed, the papers' purpose is to inform the ongoing initiative itself and provide detailed but accessible overviews of the main issues and themes underpinning negotiations towards a comprehensive post-2012 international climate change agreement. They are an important and accessible resource for political and business leaders, climate change professionals, and anyone wanting to understand more fully, the key issues shaping the international climate change debate today.

The views expressed and information provided in this paper are the sole responsibility of the author. The Climate Group, the Office of Tony Blair and the staff of Breaking the Climate Deadlock Initiative accept no responsibility for any errors of fact or the opinions contained herein.

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Executive Summary

- Carbon Capture and Storage (CCS) can play an important role in the portfolio of mitigation options after 2020-2030. Several scenarios project CCS to account for over six gigatonnes of carbon dioxide (equivalent) per year ($GtCO_2$(e)/yr) reduction in 2050, or more than 20 percent of the total required greenhouse gas (GHG) abatement. Most of the storage takes place in developed countries and in emerging economies in Asia.
- CCS is the only technology that allows deep CO_2 reductions in fossil-fuel based power and industry sectors.
- For most countries, storage potential near CO_2 sources is likely to be large, but for some countries finding suitable storage sites could prove difficult.
- CCS will increase the cost of electricity, but the mitigation costs are in the same range as many other (competing) options, and will decrease the overall cost of stabilisation targets.
- Modelling studies suggest that a carbon price in the order of \$30/tCO_2 would be required before CCS becomes a viable option for reducing GHG emissions in the power sector. Stabilisation around this price level may be sufficient to provide investors with the confidence required to make long-term investments.
- However, in the short and immediate term the CO_2 market price may need to be as high as \$60-100/tCO_2, in view of the financial and technological risks still related to CCS, and the volatility of the CO_2 market price.
- In industry and energy production, there are several lower cost CCS options, below \$15/tCO_2, which could provide “early opportunities”.
- Key success factors in the near term include demonstration of full CCS systems in the power sector, public support, and establishment of a legal and regulatory framework.

Recommendations

- Demonstration of full CCS chain in the power and industry sectors in Annex I (industrialised) countries.
- Build confidence about post-2012 climate action.
- Setup a mechanism for funding of CCS demonstration in non-Annex I (developing) countries, and consider responsibly including CCS in the Clean Development Mechanism (CDM).
- Discuss financing options and commit funds, including a technology transfer fund; resolve Intellectual Property Rights (IPR) issues.
- Pledges to build no coal-fired power stations without CCS after 2020 in Annex I, and after 2030 in non-Annex I countries.

Carbon Capture and Storage

This paper explores opportunities for Carbon Capture and Storage (CCS) technologies to abate carbon dioxide under anticipated conditions of continued fossil fuel use, and sets out the need for early demonstration of the technologies to overcome barriers to their deployment. The paper covers:

- CCS technology and its role in global mitigation scenarios
- The maturity of the various components of CCS technology
- Costs and required investment
- Policy issues and barriers to be overcome

An introduction to carbon capture and storage

What is CCS?

Through CO_2 capture and geological storage, CO_2 that would otherwise be emitted into the atmosphere and cause climate change, is kept underground.

Carbon Capture and Storage (CCS) consists of three components. Firstly, from a large point source such as a power plant, cement factory or gas processing installation, the carbon dioxide (CO_2) is separated from the flue gases. Secondly, it is transported, by pipeline or ship, to a suitable storage location. Lastly, it is injected in a suitable geological reservoir, such as a depleted gas field, where it is retained permanently.

Why is CCS an important technology?

Preventing climate change under conditions of continued coal use requires CCS.

CCS may contribute simultaneously to meeting objectives of environmental sustainability, economic competitiveness and security of energy supply. CCS is the only technology that can substantially mitigate greenhouse gas emissions from fossil fuel combustion from large stationary sources, notably from coal in power and various industrial sectors, including cement, oil and gas production and refining, iron and steel manufacturing and chemicals. Should our energy system eventually include more electricity or hydrogen in buildings and transport, then we will need to expand power and hydrogen production facilities with CCS.

In the coming century, greenhouse gas emissions are projected to rise steeply, perhaps 25-90 percent between 2000 and 2030[1]. In such a scenario, fossil fuels are projected to maintain their dominant position in the global energy mix to 2030 and beyond. Two thirds to three quarters of this increase in energy-related CO_2 emissions is projected to come from developing countries.

While it is generally recognised that no single mitigation measure will be sufficient to achieve an acceptable GHG stabilisation level, the considerable reserves of coal worldwide suggest that CCS will need to play an important role in the global climate change mitigation portfolio. To date, a range of CO_2 storage projects have shown that CO_2 may be injected and stored safely at great depths, including for instance the Sleipner project (at the Norwegian coast, since 1996) and the Weyburn project (in Canada, since 2000).

Without CCS the cost of GHG emission reduction pathways are more expensive. In fact, the costs of stabilising CO_2 concentrations would be reduced by 30 percent or more if CCS is included in a mitigation portfolio[2]. In the International Energy Agency's (IEA's) optimistic Accelerated Technology (ACT) scenarios, which are compatible with 550 parts per million by volume (ppmv), GHG concentration would, without the benefit of CCS[3], need marginal abatement cost increases in 2050 of $25-43 in Europe and $40 in China, per tonne of CO_2e. For 550 ppmv stabilisation scenarios, models calculate a share of 15-55 percent of CCS in global CO_2 reductions[4].

Recently, the high costs of construction materials and engineering have pushed the cost of CCS upwards. While this trend may be temporary, some of the price increase could last.

CCS in global mitigation scenarios

CCS can play an important role in the portfolio of mitigation options in the next decades.

CCS is not expected to be commercialised before 2020, but in 2030 the global CO_2 reduction by CCS could be in the order of several gigatonnes of CO_2 per year, after which its significance is likely to increase. Economic modelling that is compatible with stabilisation at a level of 550 ppmv relative to baseline levels, suggests that CCS will account for 10-35 percent of the total CO_2 reduction in 2050, i.e. up to 10 $GtCO_2$/yr[5]. For comparison: global GHG emissions were 49 $GtCO_2e$ in 2004[6]. If projections on the contributions to global CO_2 reduction that are likely through CCS are to materialise, there is an apparent need to accelerate the introduction of large-scale CCS operations.

In the IEA's ACT Map[7] scenario CCS accounts for 6 $GtCO_2$ of emissions reduction in 2050[8]. The following table shows the contribution of CCS to the total CO_2 reduction in 2050 in this scenario and its four variants[9]. The remaining reduction in these scenarios is covered mainly by end-use energy efficiency and to a lesser extent increased use of renewables.

Exhibit 1

Estimated contribution of CCS to total CO_2 production in 2050

Source
IEA (2006)

Sector	Share of CCS in total global CO_2 reduction in 2050
Power generation	12-18%
CTL, GTL, refineries and H_2 production	3-5%
Industry	4-6%

** CTL: coal-to-liquid; GTL: gas-to-liquid*

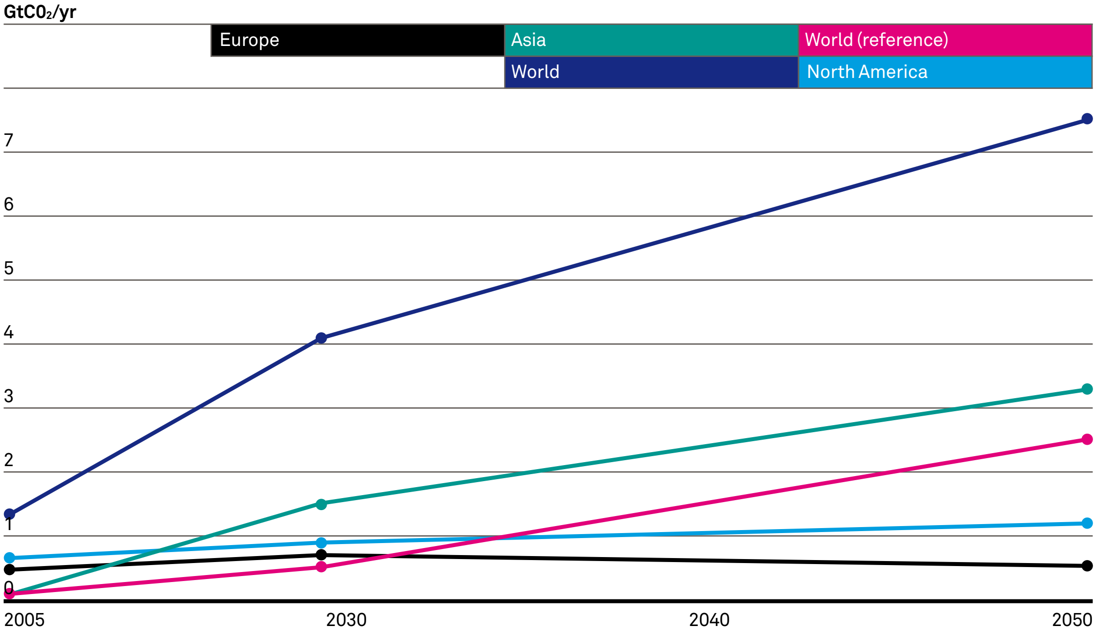
The EU's World Energy Technology Outlook (WETO-H_2) study[10] investigated a reference and a carbon-constraint scenario:

- In their reference scenario: global CO_2 emissions in 2050 are projected to have risen by 120 percent compared to 1990, the carbon price is projected to be €5/tCO_2, and around 2.5 $GtCO_2$ would be stored in 2050.
- The carbon constraint scenario, by contrast, with a CO_2 market price of €58/tCO_2 in 2050 and global CO_2 emissions of 25 percent above 1990 levels, shows a very large amount of CO_2 storage. In this scenario, out of the 6.4 $GtCO_2$ that would be stored globally in 2050, Asia would account for about half, and Europe and North America 9 and 17 percent respectively.

The IPCC[11] foresees a slightly different distribution to that in the above constraint scenario (although over a different timeframe); in the average of their scenarios leading to 550 ppmv, Asia takes 33 percent and OECD 27 percent of total CO_2 storage in the 21st century.

While Greenpeace[12] shows that mitigation CO_2 reduction paths consistent with 2°C temperature increase can also be attained without CCS, i.e. by an ambitious package of energy efficiency and renewables, CCS is likely to be critical in meeting long term targets for atmospheric stabilisation of greenhouse gases.

Exhibit 2



CO_2 storage in WETO-H_2 carbon constraint case[13]

Most estimates of the global geological storage capacity are in the range of 1000-2000 $GtCO_2$, indicating sufficient storage possibilities for the total amount of CO_2 captured in most 450 and 550 ppmv scenarios[14]. Most of the potential is in saline aquifers, but as these are often not studied well, the uncertainty is very large. On a regional level however, the picture may change. North America, Russia and the Middle East have ample storage capacity, but in Europe, many Asian regions and Latin America, estimates show smaller numbers. For many countries, including China and India, the quest for appropriate storage capacity is ongoing and outcomes are uncertain.

Interaction between CCS and energy efficiency

In order to combat climate change, a portfolio of mitigation technologies is required, which interact and compete with each other in a number of ways. Deployment of CCS will depend on the development and the costs of competing technologies such as renewables and nuclear[15]. Increased energy efficiency could decrease the requirement for CCS in the power sector. However, the decarbonisation of buildings, industry, and transport sectors could lead to enhanced centralised production of electricity and hydrogen as the energy carriers for these sectors, leading to more CCS.

The IPCC[16] identified an economic potential of approximately 4 $GtCO_2$/yr in 2030 for electricity savings in industry and buildings at a cost lower than \$100/tCO_2. Assuming that the reduction in power demand is completely covered by reduced construction of fossil-fuelled power plants, this figure could represent the reduced requirement for CCS. However this is likely to be an overestimation, as the difference will probably be covered by a mix of renewables, nuclear and fossil plants. In the IEA's 'ACT low energy efficiency'[17] scenario the improvement in energy efficiency is 0.3 percent lower than in the ACT Map[18] scenario, which results in an increase of 6 $GtCO_2$ in 2050. This needs to be covered by other technologies, including CCS in the power sector and fuel transformation.

CCS technological maturity

The different components of CCS have been successfully commercialised, but a full CCS chain in the power sector, which is likely to be essential for curbing global CO_2 emissions, is yet to be demonstrated.

For each of the components of CCS – capture, transport and storage – different technologies can be used. Exhibit 3 shows the maturity of these technologies[19].

Exhibit 3

Maturity of CCS technologies[20]

CCS component	CCS technology	Research phase	Demonstration phase	Economically feasible under specific conditions	Mature market
Capture	Post-combustion			●	
	Pre-combustion			●	
	Oxyfuel combustion		●		
	Industrial separation (natural gas processing, ammonia production				●
Transportation	Pipeline				●
	Shipping			●	
Geological storage	Enhanced Oil Recovery (EOR)				●
	Gas or oil fields			●	
	Saline formations			●	
	Enhanced Coal Bed Methane recovery (ECBM)[f]		●		
Ocean storage	Direct injection (dissolution type)	●			
	Direct injection (lake type)	●			
Mineral carbonation	Natural silicate minerals	●			
	Waste materials		●		
Industrial uses of CO_2					●

For capture, the most costly component, several industrial applications are already commercial. Pre- and post-combustion applications are not yet fully commercial and oxy-fuel combustion is only in the demonstration phase. Current capture technologies involve physical or chemical solvents. Regeneration of chemical solvents requires additional heat and thereby implies an 'energy penalty' in the overall process, e.g. power production. Research is ongoing in the improvement of this process, as well as other capture processes such as membrane separation, cryogenic separation and using solid sorbents. This could reduce the overall energy requirement, and the cost of capture.

Post-combustion technology can be used in modern pulverised coal (PC) and natural gas combined cycle power plants, as well as in production of steel and cement. Oxy-fuel combustion capture systems could provide advantages over post-combustion in these applications, as the energy-intensive step of CO_2 separation is not required. However, production of pure oxygen requires energy, and more research is needed to prove the advantages. Depending on technological development oxy-fuel combustion in power production could become competitive with pre- and post-combustion[21]. It could also be the preferred option for co-disposal of nitrogen oxides (NOx), sulfur dioxide (SO_2), mercury and CO_2[22].

Pre-combustion capture can be applied in integrated gasification combined cycle (IGCC) power plants or the production of low-carbon hydrogen. The fuel is first converted into synthesis gas (H_2 + CO), and the CO converted into CO_2, which is then separated from the hydrogen. Compared to PC power production the cost of capture is lower, due the higher CO_2 concentration in the separation stream. Other applications include hydrogen and ammonia production. Most likely, all of these technologies will need to play a role in an effective climate change mitigation portfolio.

For transport of CO_2, no major technical issues are identified.

CO_2 would be injected in a supercritical form in geological storage reservoirs, usually at depths greater than 800m. There are a number of potential reservoirs that can be used:

- **Enhanced oil recovery (EOR)**: the injection of CO_2 into an operating oil field can provide a driver for more oil recovery. The revenues could compensate part of the CCS costs. EOR (using CO_2 from natural CO_2 accumulations underground) has been done on a large scale in North America since the 1980s. Enhanced gas recovery may also be an option.
- **Saline aquifers**: the most widespread type of CO_2 storage reservoirs are underground formations that contain very salty water (brine) in which the CO_2 is injected. The Sleipner project in the North Sea is a large-scale demonstration of this.
- **Depleted oil/gas fields**: A depleted oil or gas reservoir has a proven caprock and can be used to store CO_2. An advantage is that, if timed right, the wells of the recovery operation can be reused.
- **Enhanced coal bed methane recovery**: storage of CO_2 in coal seams that cannot be mined. The CO_2 adsorbs to the coal, releasing the methane that naturally occurs in coal seams. This methane can be recovered and used.

Cost and investment required

Cost of electricity and CO_2 abatement cost

CCS will increase the cost of electricity, but the mitigation costs are in the same range as many other (competing) options.

Applying CCS can increase cost of electricity (COE) significantly. Capture costs are currently \$29-51/tCO_2 (post-combustion, new PC plant) and \$13-37/tCO_2 (pre-combustion, new IGCC plant). For industrial applications the capture costs are lower. Transport costs are mostly in the range of \$1-8/tCO_2, and storage costs are generally in the same range. Up to distances of 620 miles, transport by pipeline is generally less costly than by ship[23].The following table summarises the IPCC's key results for new-build power plants in \$2002.

Exhibit 4

IPCC CCS cost in new power plants[24]

	PC plant	NGCC plant	IGCC plant
Increased fuel requirement (%)	24-40	11-22	14-25
Incremental cost of CCS (\$/MWh)	19-47	12-29	10-32
Mitigation cost (\$/tCO_2 avoided)	30-71	38-91	14-53

PC: pulverised coal combustion; NGCC: natural gas combined cycle; IGCC: integrated gasification combined cycle

In 2007 the IPCC[25] reported abatement costs for CCS in new coal-fired power stations in 2030 of \$22-42/tCO_2 avoided. For gas-fired power plants the range is \$43-79/tCO_2 avoided. These figures are comparable to those identified by the IPCC in 2005[26]. Capture takes the largest part of the cost. For retrofits in existing coal-fired power plants the capital cost of CCS could be 50 percent higher than for new-build plants[27]. For industrial applications such as hydrogen or ammonia production, and natural gas processing, the costs are lower: \$5-55/tCO_2 net captured. Other industrial applications are likely to be more expensive.

Total investment in mitigation scenarios

In the UNFCCC Dialogue paper on investment flows[28] the mitigation scenario would require \$63 billion additional investment up to 2030 for CCS facilities in coal and gas-fired power plants, of which nearly half would be in non-Annex I countries. For industry the additional investment would be \$25 billion. The total investment would be \$432 billion globally.

Investment numbers are hard to establish and have many uncertainties. In the IEA's ACT Map scenario[29] the additional investment in power generation for CCS amounts to \$900 billion between 2005 and 2050. WETO-H_2[30], for a comparable amount of CCS in 2050, reports \$100-300 billion up to 2050. The WETO figures are based on a contribution of 70 percent to CCS from power production with cost between \$22 and \$42/tCO_2 avoided, 30 percent from other activities, with cost between \$5 and \$55/tCO_2 avoided, and no revenues from EOR. The scenario results in a linear cost increase between 2015 and 2050 (see Exhibit 2).

A host of projects have been proposed world wide. The European Union (EU) for instance aims to build 10 to 12 demonstration plants by 2015[31], although the time span required to realise these may run to 2020. The realisation of these plants will be a vital first step for eventual scaling up of CCS to a level that will allow it to substantially contribute to the global abatement of CO_2 emissions. The estimated total cost of constructing 10-15 plants by 2020 is approximately $2.5-7.5 billion, or $250-500 million per plant.

Policy issues and barriers to be overcome

Key factors for the successful demonstration of full CCS systems in the power sector in the near-term are public support and the establishment of a legal and regulatory framework.

Obstacles to widespread deployment

Barriers and obstacles to widespread deployment of CCS are often summarised in four overarching categories: technological, economic, legal/regulatory and social. The extent to which these barriers are felt depends much on the regional circumstances. In the EU, for instance, legal and regulatory barriers are lower than in most other parts of the world as a regulatory framework is in the process of being finalised, but in the US, public and stakeholder acceptance is higher; most environmental organisations have spoken out in favour of CCS. The picture sketched below aims to give a general picture that can differ considerably depending on local circumstances.

1 Technological barriers

Technological barriers to CCS differ according to the applications of the technology. Exhibit 3 above already shows that several components of CCS are technologically mature, and that a full CCS operation can be constructed from mature components. Scaling up, particularly for CO_2 capture in the power sector, might, however, still pose technological challenges. For this, no full-scale demonstrations have been implemented so far, although many proposals have been developed by electricity companies all over the world. Capture of CO_2 from other sources, particularly those with high CO_2 concentrations, such as fertiliser plants, gas processing installations and coal-to-liquids plants, is not expected to pose technological barriers as the technology is already being used in other applications at the scale required and is relatively straightforward.

It is often debated whether storage suffers from technological or only social barriers. Many geologists and scientists argue that injection of CO_2 in geological reservoirs is fundamentally understood, that analogous technologies such as natural gas storage and acid gas injection provide much experience, and that the application of existing technologies to contain and monitor the CO_2 is all that is needed. However, at the same time, storage of CO_2 on the scale and in the variety of reservoirs required for structural CCS deployment has not yet been demonstrated, risk assessment methods are still untested and for some reservoirs incomplete, and questions remain as to whether monitoring techniques are good enough. Good data on CO_2 permanence in geological reservoirs are sparse, and are only collected in a few large-scale projects, such as the Sleipner project in Norway and a number of EOR operations. In any case, unfamiliarity with CO_2 storage is a barrier to its implementation as it feeds unrest and inhibits public acceptance.

2 Economic barriers

Economic barriers to CCS clearly involve the high costs, particularly in the power sector. Capture costs form the highest barrier (see above). However, not only the costs themselves, but also the uncertainty of costs is a major barrier, particularly for policymakers. With no demonstration projects in place and soaring commodity prices, the present estimated incremental costs might rise considerably. On the other hand, learning benefits will bring down costs. Overall, cost uncertainties are large, even though the technology is not entirely new.

A major barrier related to economics and regulatory environment is the absence of a sufficient incentive to undertake CCS. The private sector and the finance sector need investment certainty. The policy environment is currently highly uncertain in most parts of the world: CCS is at present not allowed in the Clean Development Mechanism (CDM) (and prices would be too low for most applications if it were); many countries do not have a carbon policy in place, and when there is one, carbon prices are generally too volatile and not high enough to provide certainty for the long term. The EU and the UK are in the process of setting up a CCS demonstration plant in co-operation with China; a country that is highly relevant because of its rapidly increasing coal-fired power capacity. A structural incentive would be needed, however, to allow CCS to make a difference in China – ideas include a technology fund (which would have to be huge), inclusion of CCS in the CDM, and technology agreements that mandate CCS[32]. In the EU the CO_2 market price so far has been too low to adequately incentivise CCS. Modelling studies suggest that CCS will come in at a price level of \$25-30/tCO_2[33], but it is likely that the price level will need to be twice as high to make up for the financial and technical risks plus the CO_2 price volatility (see above). Lewis and Curien[34] argue that until CCS is competitive, a switch from coal to natural gas is likely to be the preferred abatement option for power plants in the EU ETS. Since the costs for such a switch are on the order of 40€/tCO_2, CCS is unlikely to be adopted as long as the CO_2 price is below that level. With ideas for carbon trading in the US only in their infancy, it is unlikely that emissions trading will provide an incentive for CCS in the near future.

3 Legal and regulatory barriers

A legal framework is important for several reasons: it limits risks of CO_2 storage, eases public concern, and provides legal certainty to the project developer, especially for long-term, post-closure liability; something that insurance companies have indicated they cannot insure. Many industrialised countries are now developing a legal framework to allow for CCS. In the US, States interested in hosting CCS demonstrations are making most progress but the federal government is slower. In Europe, the European Commission has proposed a general legislative framework, but the Member States still need to implement it in detail. In Australia, the government is seeking public comments on a draft legal framework. International treaties, such as the OSPAR (refer glossary) and London Conventions, have been adjusted to accommodate CCS. This does not mean that all countries have a legal framework, but it does illustrate that examples exist and that progress has been fast over the past couple of years.

At this point, it is unclear whether intellectual property rights (IPR) pose a serious barrier to CCS deployment, especially in developing countries. Studies on this have not yet been implemented, and statements by private companies, the owners of the complex technology especially on the capture side, have been ambiguous. This is an area where additional research would be useful.

4 Social and public perception

Perhaps the least tangible and most complex barrier relates to public support for CCS. Public perception studies have shown a "reluctant rather than enthusiastic" attitude towards CCS. It is likely that attitudes are more sceptical if storage is foreseen "in people's backyards". The environmental movement has been divided on CCS. Whereas several NGOs (WWF, NRDC, ED, Bellona Foundation) promote it as the third option after energy efficiency and renewable energy (thus making nuclear unnecessary), others view it as an option that comes too late and provides too few benefits[35]. CCS is not considered to be a sustainable energy option and the danger that CCS would divert resources from other energy options and thus delay the transition away from fossil fuels is perceived as a problem[36]. Organisations that question the use of CCS ask why we would want to invest many billions of dollars in an option that bears risks and that will anyway be exhausted within a couple of hundred years. The contention that low stabilisation levels can be reached without using CCS or nuclear seems to be at the basis of the disagreement – organisations that believe climate change can be solved through energy efficiency and renewable energy alone, tend to oppose CCS. Those environmental organisations that feel CCS is needed to prevent climate change tend to favour it[37].

What could we do now to bring forward large-scale deployment by a decade?

Many of the barriers identified in the preceding section relate to the novelty of CCS as a technology. To ensure rapid development of CCS, all barriers would ideally be addressed at the same time, but this is a considerable challenge. In fact, for CCS, the "valley of death" for new technologies looms. To bridge the gap between highly developed technology and the commercial market, large-scale demonstrations are needed to bring down costs, build public confidence, and create political will for the right policy environment. It is on this phase that short-term efforts would be most useful. Also, efforts in emerging economies could focus on awareness raising, knowledge and capacity building, mapping potential underground storage, developing a legal framework, educating the public, and perhaps implementing CCS-ready power plants and CO_2 storage demonstrations.

What deployment scenario for CCS could be imagined?

If the world, by 2020, can implement perhaps 10-20 full-scale demonstrations in a variety of CO_2 sources, geological reservoirs, and countries, it is expected that most of the early barriers already highlighted in the section above can be overcome. It should be noted that the largest barrier is likely to be the funding for large-scale demonstrations, which will cost in the order of $10 billion. Other barriers, notably public acceptance of the technology as one of the options in the global mitigation portfolio, but also legal frameworks in all relevant countries including emerging economies, require funding of flanking activities, including international technology transfer.
A way to kick-start CCS is to look for early opportunities first. The IPCC[38] has already identified several sectors as having low capture costs but considerable potential: gas processing (currently implemented in the Sleipner, In Salah, K12B and Snøhvit projects in Europe and Africa), fertiliser plants, coal-to-liquid facilities and several other sources with high-CO_2 exhaust streams and hence very low capture costs. These early opportunities would build confidence and experience in CCS with respect to storage, legislation, selecting good CO_2 storage sites, predicting site integrity, and monitoring storage sites, without incurring high capture costs. Some of these options have a high potential – if China and the US, for instance, embark upon a coal-to-liquids path for energy security reasons, CCS would be essential to prevent the GHG consequences from skyrocketing. Experiments with biomass co-firing and CCS could also be implemented as a more CO_2-extensive way of implementing these options, and potentially gaining more public acceptance for CCS by making it CO_2-negative. If these early opportunities are successful, the much larger investments required for structural CCS deployment in the power sector can be done with more confidence.

Eventually, in order to arrive at low stabilisation levels, from 2020 no coal-fired power plant should be built in the industrialised world without CCS. From 2030 (or thereabouts), the same should apply to the emerging economies.

What key decisions need to be made?

In light of the need to get CCS through the demonstration phase, decisions are necessary to implement various CCS proposals over the next 10 years. The EU's proposed initiative to build 10-12 full-scale demonstration plants by 2020 is the most concrete example awaiting approval. It remains unclear, however, whether the considerable funding for these demonstration plants will be found. In addition to the EU, other countries are looking into demonstrations. Whether it is in China, the US, India or Saudi Arabia, costs of CCS will come down quicker if a better understanding is gained of geological structures, and of sources of CO_2, in a broader array of countries. For demonstration in developing countries, allowing CCS in the CDM would help, or an alternative mechanism (such as a fund) could be considered.

It is important to realise that without a clear policy signal, CCS will not be able to make a contribution to climate mitigation. Following such a clear signal, higher carbon prices ideally would structurally deploy CCS. For this, an international framework on climate change would be necessary, although some countries or regions might install stringent climate policies on their own (such as the European Union has recently announced). The recent developments in Bali have made an international agreement more likely, but an outcome that would spur CCS is by no means certain at this point. The demand for credits under the CDM, and hence the potential for CCS under the CDM if permitted, will also depend on an international carbon price.

However, an international carbon price is not the only possible international agreement for CCS. Currently, the Carbon Sequestration Leadership Forum (CSLF) provides for the exchange of knowledge and a limited degree of research coordination, but its role is extremely limited. A CCS-specific agreement (sometimes called a sectoral or technology-oriented agreement) might be among future possibilities. Such an agreement could comprise joint research, development and demonstration, as well as technology transfer, but it could also make provisions for more structural deployment, such as in an old proposal by Edmonds and Wise[39]. Such an agreement would lead to considerably higher costs than a carbon trading based agreement, but would be more tangible in terms of what its results and costs would be. The European Commission has actually considered something along those lines: it has investigated the possibility of imposing a mandate on CCS for coal-fired power plants from 2020 in case carbon prices are not high or stable enough by then.

Glossary of Terms

ACT:	Accelerated Technology
CCS:	Carbon Capture and Storage
CDM:	Clean Development Mechanism
CO_2:	Carbon dioxide
COE:	Cost of Electricity
CSLF:	Carbon Sequestration Leadership Forum
ED:	Environmental Defence
EOR:	Enhanced Oil Recovery
ETS:	Emissions Trading Scheme
EU:	European Union
GHG:	Greenhouse Gases
Gt:	Gigatonnes
IGCC:	Integrated Gasification Combined Cycle
IPCC:	Intergovernmental Panel on Climate Change
IPR:	Intellectual Property Rights
NDRC:	Natural Resource Defence Council
NGCC:	Natural Gas Combined Cycle
NGOs:	Non-Government Organisations
NOx:	Nitrogen Oxide
OECD:	Organisation for Economic Co-operation and Development
OSPAR:	Convention for the Protection of the Marine Environment of the North-East Atlantic
PC:	Pulverised Coal Combustion
ppmv:	Parts Per Million by volume
SO_2:	Sulphur Dioxide
UNFCCC:	United Nations Framework Convention on Climate Change
WETO:	World Energy, Technology and Climate Policy Outlook
WWF:	World Wildlife Fund

Endnotes

[1] IPCC (2007) Climate Change 2007: Mitigation. Contribution of Working Group III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change [B. Metz, O.R. Davidson, P.R. Bosch, R. Dave, L.A. Meyer (eds)], Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.AR4 mitigation.

[2] IPCC (2005): IPCC Special Report on Carbon Dioxide Capture and Storage. Prepared by Working Group III of the Intergovernmental Panel on Climate Change [Metz, B., O. Davidson, H. C. de Coninck, M. Loos, and L. A. Meyer (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, 442 pp.

[3] This is exemplified in the Accelerated Technology (ACT) scenarios in: IEA (2006) Energy Technology Perspectives. Scenarios & strategies to 2050, in support of the G8 Plan of Action. OECD/IEA, Paris.

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[5] Ibid.

[6] IPCC (2007), op. cit.

[7] The ACT Map scenario assumes relatively optimistic progress across all energy technology areas (e.g. renewable, nuclear, CCS, fuel cells, and biofuels) and a 2 percent p.a. improvement in global end-use efficiency. IEA (2006), op. cit.

[8] IEA (2006), op. cit

[9] The four ACT variants are: 'Low Renewables'; ' Low Nuclear'; 'No CCS'; and 'Low Efficiency'

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