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Acceptability of CO_2 capture and storage

A review of legal, regulatory, economic and social aspects of CO_2 capture and storage

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Summary

Capture and storage of CO_2 (CCS) has been studied as an option in the portfolio of climate change mitigation strategies for about 20 years. Now that the actual structural, large-scale application of the technology runs nearer, it is becomes clear that CCS has a number of aspects that may inhibit its deployment. The aim of the ACCSEPT project[1] is to identify the main gaps in knowledge in the non-technical aspects of CCS, to research them, and to propose recommendations to address them.

This report provides a critical literature review for the non-technical aspects of CCS in the following categories:

- Legal issues: From a legal point of view, main gaps appear to relate to domestic law. In particular, analysis is required of the extent to which current EU and national legislation regarding property rights and liability might apply to CCS activities. Preferably, existing regulatory arrangements will be utilised and, where necessary, amended to fill gaps and provide certainty. Public international law's relevance to CCS is better known; clarification (and possibly amendment) is required of several provisions in the marine protection treaties, which have the potential to act as a barrier to CCS activities.
- Regulatory issues: Guidance on CCS is required under the international climate change regime before it can be broadly deployed. The main current showstopper is that the permitting requirements for site-selection and long-term monitoring. It would be preferable if an international institution with indisputable credibility would develop standards related to those issues, which could then be used for national legislation as well as for international instruments such as the EU Emissions Trading Scheme and the CDM.
- Costs and economics: Strictly in terms of economic aspects of CCS, there are no real showstoppers for the development of CCS. However, there are several aspects that, despite the role they play in policymaking, do not receive sufficient attention and may lead to misinformed decision-making. Firstly, major models appear to use low values for the costs of CCS, which would result in an overestimation of the role of CCS in the mitigation portfolio. Secondly, the difference in relative increase of the electricity price following large-scale application of CCS (as well as other mitigation options) around the globe might negatively influence acceptance of the public in regions with low electricity prices.
- Social and acceptability issues: In several other technology fields, such as nuclear energy and genetically modified organisms, unexpected public opposition has halted progress. The public is not well informed about CCS, although that might be changing with enhanced media attention. The limited and in several cases incomparable research into public perception of CCS yields a more neutral than negative opinion on CCS, and also points at two contextual conditions for CCS acceptance: climate change should be recognised as a problem, and significant CO_2 reduction as the only solution. The position of NGOs can also change the perception of a technology. At this point, their position varies highly, although none are vehemently against CCS as such, but also none favour it over renewable energy or energy efficiency. The NGO position is normally inspired by more nuanced conditional aspects: according to some, CCS should for instance not divert resources from renewable energy and energy efficiency, and it should therefore not be sponsored by R&D money or by specific policy measures.
- Crosscutting issues: several crosscutting issues were identified: the overall potential of geological storage and the difficulties in determining reservoir suitability, the upstream greenhouse gas emissions of CCS and externalities associated with continued use of fossil fuels, and the availability of affordable fossil fuels over the coming 50 years.

[1] Acceptance of Carbon dioxide Capture and Storage Economics, Policy and Technology. European Commission DG Research project, led by DNV, with partners Baker&McKenzie, ECN, IEEP and Tyndall.

- In the context of the ACCSEPT project, a workshop was held with a small group of experts in different fields from government, industry, NGOs, and academia. The report ends with a number of issues that came up in those discussions in the fields of mitigation portfolio and decentralisation, public perception and policy and legislation.

1. Introduction

Capture and storage of CO_2 (CCS) has been studied as an option in the portfolio of climate change mitigation strategies for about 20 years. Although the technical maturity of CCS is generally less than other mitigation options, such as renewable energy or energy efficiency, many of the CCS components are generally regarded as mature enough for deployment (IPCC, 2005). CCS, however, has a number of other aspects that may inhibit its deployment. The aim of the ACCSEPT project[2] is to identify the main gaps in knowledge in the non-technical aspects of CCS, to research them, and to propose recommendations to address them.

Although in the recent past several large and influential reports have been published in the field of CCS, many of them have focussed on the technical aspects of CCS. The IPCC Special Report on CCS did not have the mandate to address policy aspects and could only touch upon public perception issues (IPCC, 2005). An IEA report (IEA, 2004) focussed on the costs and economic aspects of CCS and touched upon regulatory and risk issues, but was at the time of publication unable to dive deep into it.

This report provides a critical literature review for the non-technical aspects of CCS in the following categories:

- Legal issues: National and international legislation relevant to CCS. Examples include national drinking water and mining laws, and the London Convention (Chapter 2).
- Regulatory issues: National and international policies in the field of energy or climate change that can act as support mechanisms for CCS (Chapter 3).
- Costs and economics: Addresses the question whether the current costs assumed for CCS are interpreted correctly, and reviews the assumptions made in economic models informing the policymaking process (Chapter 4).
- Social and acceptability issues: A review of all studies currently done that focus on public perception of CCS. Methods used are questionnaires with lay public, focal group discussions, and expert polls (Chapter 5).
- Crosscutting issues: CCS as a bridging option, energy use of CO_2 capture, global storage capacity estimates, availability of fossil fuels, and the environmental externalities of fossil fuel use (Chapter 6).

Each review of the topics leads to a number of questions and gaps in knowledge that remain unresolved, and that are summarised in the 'preliminary gap analysis' (Section 7). The analysis has served as a basis for further discussion of these issues in a stakeholder workshop, held on April 25 and 26, 2006, in Gent (Belgium). The participants of the workshop, twelve in total complemented by the project team, represented a broad range of stakeholders, including government, oil industry, electricity industry, academia, and environmental NGOs. The workshop notably did not attempt to reach consensus on the topics discussed, but merely meant to flag controversies and develop a common language among the diversity of attendants. The discussions were grouped into three main topics: CCS in the energy system, public perception, and regulation. The major conclusions are summarised in Chapter 8.

[2] Acceptance of Carbon dioxide Capture and Storage Economics, Policy and Technology. European Commission DG Research project, led by DNV, with partners Baker&McKenzie, ECN, IEEP and Tyndall.

2. Legal issues

The review of the legal issues surrounding CCS focuses on public international law in the first section, and on domestic (EU) law in Section 2.2.

2.1 Public international law

From an international perspective, this report will concentrate on legal barriers to the effective development of CCS in light of existing international regimes. It should be noted that, although they contemplate CCS as a mitigation option, the UNFCCC and its Kyoto Protocol do not expressly include or exclude CCS as an emission reduction device, giving rise to credits. In order for CCS to enjoy the benefits provided under the Kyoto Protocol, its status must be clarified (IEA, 2005). With regards to the CDM, at COP/MOP 1 it was decided that further consideration needed to be given to the eligibility of CCS as a CDM activity, taking into account project boundaries, leakage and permanence. Further guidance is expected at COP/MOP 2. The issues associated with CCS under the international climate change regime are comprehensively discussed in the following section on regulatory issues.

Because the international legal framework is relevant primarily to offshore storage, many of the potential legal barriers derive from the marine protection treaties. Importantly, any treaty amendments that may be required will involve further negotiations, a minimum level of support, and will amend earlier treaties only for those Parties that ratify the amendments (IPCC, 2005).

There are several other international agreements that are possibly applicable to CCS. These include the Convention on Environmental Impact Assessment in a Transboundary Context (Espoo Convention), the Basel Convention on the Control of Transboundary Movements of Hazardous Wastes, and the Convention on Biological Diversity (Flory *et al*, 2005). They pose less of a challenge to CCS development and are not generally considered in the literature. Accordingly, this report will focus on the marine protection treaties.

2.1.1 The UN Convention on the Law of the Sea 1982 (UNCLOS)

UNCLOS (which entered into force in 1994) is an overarching convention and, as such, does not contain detailed provisions on most maritime issues. Rather, it provides a framework for all areas, including marine protection, and allows other, more targeted treaties to fill in the gaps. Although UNCLOS is expressed as applying to the seabed and its subsoil, the literature tends to support the view that it would also apply to CCS *beneath* the subsoil (Scott, 2005). Nevertheless, clarification on this point is required.

UNCLOS divides the ocean into zones: the territorial sea, the exclusive economic zone (EEZ), the continental shelf and the high seas. Accordingly, States' rights and responsibilities will vary depending on the location of CCS activities. In essence, coastal States have jurisdiction over their territorial sea, EEZ and continental shelf, and may therefore prescribe additional regulations within these areas or prohibit CO_2 'dumping' altogether. Note, however, that there is some uncertainty about the rights of coastal States in relation to disposal of CO_2 via pipeline into the EEZ or continental shelf. With regards to the high seas, CO_2 disposal is a freedom which may be exercised by all States provided that they have due regard to the interests of other States and the requirements of international law (Churchill, 1996).

Regardless of location, States must observe the provisions on protecting the marine environment. These provisions will apply if the proposed activity is determined to be 'pollution', which is defined as:

> *The introduction by man, directly or indirectly, of substances or energy into the marine environment, including estuaries, which results or is likely to result in such deleterious effects as harm to living resources and marine life, hazards to human health, hindrance to marine activities, including fishing and other legitimate uses of the sea, impairment of quality for use of sea water and reduction of amenities.*

Under UNCLOS, States are obliged to take all measures necessary to prevent, reduce and control pollution of the marine environment from any source. They must also ensure that activities under their control are conducted so as not to cause damage by pollution to other States and their environment, and that pollution arising from incidents under their control does not spread beyond the areas where they exercise sovereign rights. The literature is inconclusive about the status of CCS as pollution (Purdy *et al*, 2004), however McCullagh (1996) comments that the input of large quantities of CO_2 is likely to result in harm to living marine resources.

In fulfilling their obligation to prevent, reduce and control pollution of the marine environment, States must act so as 'not to transfer, directly or indirectly, damage or hazards from one area to another or transform one type of pollution into another'. It is unclear how a practice of reducing atmospheric CO_2 through the use of marine storage would be interpreted in this context (IEA GHG, 2003).

2.1.2 The London Convention 1972 and its 1996 Protocol

The purpose of the London Convention is to control the input of substances into the sea. It administers a blacklist of substances, the dumping of which is prohibited, and a 'reverse list' containing substances which may be conditionally dumped under strict control.

Dumping is defined as 'any deliberate disposal at sea of wastes or other matter from vessels, aircraft, platforms or other man-made structures at sea', but does not include 'placement for a purpose other than the mere disposal thereof, provided that such placement is not contrary to the aims of the Convention.' Because this definition only refers to ships, aircraft and offshore platforms, it would seem that CO_2 disposal, from a land-based pipeline does not fall under the purview of the Convention (Heinrich, 2002). Some commentators argue that the Convention also does not apply to CCS in the ocean seabed or its subsoil because the definition of 'sea' is 'all marine waters other than the internal waters of States' (Purdy *et al*, 2004). Nevertheless, it could be argued that the scope of the Convention extends to the seabed if activities there have the potential to harm the sea (IEA, 2005).

CO_2 is not specifically mentioned in either the blacklist (Annex 1) or reverse list (Annex 2) of substances. However, it has been suggested that CO_2 might be classified as an 'industrial waste': a black-listed substance defined as 'waste materials generated by manufacturing or processing operations'. The literature points out that this definition is ambiguous and open to varying interpretations. According to the Convention's Scientific Group, CO_2 resulting from the use of fossil fuels is an industrial waste, and its disposal into the oceans (including the sub-seabed) would therefore violate the London Convention (Wilson *et al*, 2003). The UK government have also commented that, in their opinion, CO_2 is an industrial waste. If CO_2 is not considered to be an industrial waste, it will not be prohibited by Annex I and will instead be subject to the permit procedure contained elsewhere in the Convention.

Another issue arising from the definition of dumping is whether 'disposal' includes 'storage'. Disposal is left undefined, but is often interpreted as the action of permanently getting rid of a substance (CO_2 Capture Project, 2003). The literature suggests that the long-term storage of CO_2

for the purpose of mitigating climate change does amount to 'disposal' (Purdy *et al*, 2004), however this is a point of contention. Because 'dumping' excludes placements for purposes other than the mere disposal of waste, it is likely that if CO_2 were to be injected for an industrial purpose (such as EOR) or for scientific research then it would be permitted under the Convention (Wall *et al*, 2004).

The London Protocol 1996, which was developed to modernise and eventually replace the London Convention, is potentially more relevant to carbon storage (IEA, 2005). Note, however, that it has not yet entered into force. Under the Protocol, the new definition of 'dumping' reads: 'any *storage* of wastes or other matter *in the seabed and the subsoil thereof* from vessels, aircraft, platforms or other man-made structures at sea' (changes italicised). This removes doubt about the definition of 'disposal' (as CCS is clearly 'storage'), and expressly covers the seabed and subsoil.

In addition, the Protocol circumvents the industrial waste definition issue by prohibiting all dumping except for acceptable wastes contained in a 'reverse list'. This list does not mention CO_2, and it is the general consensus that CO_2 does not fall within any of its categories (Purdy *et al*, 2004). Sea dumping under the Protocol does not include pipeline discharges from land, operational discharges from vessels or offshore installations or placement for a purpose other than the mere disposal thereof, if not contrary to the aims of the Protocol. Subject to these exceptions, the London Protocol appears to prohibit the storage of CO_2 both in the water column and in sub-seabed repositories (IEA, 2005).

The Protocol also contains a stricter approach to the precautionary principle than the London Convention, as it requires Parties to apply it, instead of simply being 'guided by' it. According to this principle, preventive measures must be taken when there is reason to believe that substances or energy introduced in the marine environment are likely to cause harm, even when there is no conclusive evidence to prove a causal relationship between inputs and their effects. CO_2 is likely to fall within the scope of this principle, however there is some uncertainty as to whether it would fail the 'likelihood of harm' test (IEA, 2005).

Ongoing work is being performed in order to conclusively determine the status of CCS under the London Convention and its Protocol. Most recently, the 27th Consultative Meeting of the Contracting Parties to the London Convention decided to convene a 'CM Intersessional Legal and Related Issues Working Group on CO_2 Sequestration' (IMO, 2005). This group met from 10 April to 12 April 2006 to develop a set of options to clarify (and, if appropriate, amend) the Protocol and the Convention, with a view to facilitating and/or regulating the use of CCS in sub-seabed geological structures. The meeting's findings are not yet available.

2.1.3 The OSPAR Convention 1992

The Convention for the Protection of the Marine Environment of the North-East Atlantic (OSPAR Convention), established in 1992 by 15 Northern European Member States and the European Community, is considered as the most comprehensive and strict legal framework governing the marine environment. It is a regional agreement applying to the waters of the Contracting Parties in the geographical maritime area around the North Sea and parts of the Atlantic and Artic oceans. The Convention requires 'all possible steps' to be taken to prevent pollution being introduced, directly or indirectly, into the maritime area. The 'maritime area' includes 'the bed of all those waters and its sub-soil'. It is probable that this definition covers CCS in the seabed and the underground strata beneath it (OSPAR Group of Jurists and Linguists, 2004).

The most widely cited interpretation of the OSPAR Convention is a report by the OSPAR Commission's Group of Jurists and Linguists giving a preliminary view on the placement of CO_2 in the maritime area.

The key messages of their report are as follows:

- Land-based sources: discharge by pipeline into the maritime area from land-based sources is not prohibited (provided it does not involve subsequent activities through a vessel or off-shore installation), but must be strictly regulated or authorised.
- Dumping from vessels: this is prohibited, unless for the purpose of scientific experimentation.
- Offshore activities:
  - Placement of CO_2 arising from the operation of an offshore installation for the purposes of EOR, climate change mitigation or mere disposal is not prohibited but must be authorised or regulated.
  - Placement of offshore-derived CO_2 for scientific research is not prohibited but must be in accordance with the Convention.
  - Placement of onshore-derived CO_2 brought to an offshore installation is permitted for experimental or EOR purposes, but is otherwise prohibited.

It is important to note that the guidance provided by the Group of Jurists and Linguists is only an initial opinion and may be subject to subsequent modification. As such, there is still a fundamental lack of certainty as to the applicability of OSPAR to CCS. The OSPAR Commission is involved in a continuing process to deal with the issues surrounding CCS.

2.2 EU and domestic law

On the domestic front, the literature focuses on issues surrounding property rights, long-term liability and the applicability of EU Directives.

2.2.1 Property rights

There is no detailed review in the literature of legislation in place in different EU Member States and its suitability for application to CCS. The literature does, however, stress the need for surface and subsurface rights to provide certainty to project proponents and governments of their entitlements and obligations. In particular, regulation should clarify the nature of property rights in stored gases, the storage reservoir and the surrounding land/seabed. Ownership rights vary between countries. For example, in the US, the land including its sub-soil at any depth can be privately owned (IEA, 2005). Conversely, in Europe, pore space is owned by the State and utilisation is addressed in the licensing process (IPCC, 2005). In that process, the State requires the developer to meet certain standards in the drilling, operation and abandonment of the underground situation. The IPCC (2005) notes that subsurface storage raises several questions other than who owns the pore space:

- Can rights to pore space be transferred to another party?
- Who owns CO_2 stored in pore space?
- How can CCS be managed so as to assure minimal damage to other property rights sharing the same space?

Furthermore, the Carbon Sequestration Leadership Forum (2004) identifies the need for property rights to be clarified in relation to transport of CO_2 by pipeline. In this context, the issues are:

- Facilitating third party access to CO_2 pipelines.
- Providing certainty in property rights for pipeline owners and users through some form of licensing regime.
- Allowing for different ownership structures of pipelines.

2.2.2 Liability

Clarification regarding the liability - particularly in the long-term - of private actors and States is vital because it may have a significant impact on the costs and public acceptance of CCS (Flory *et al*, 2005). Literature specifically addressing liability regimes for CCS is sparse. De Figueiredo *et al* (2003) note that liability for geological carbon storage derives from three major sources:

- Operational liability: the liability associated with capture, transport and injection of CO_2.
- Climate liability: the liability under regulatory climate change regimes associated with leakage of CO_2 from storage reservoirs (i.e. deviations from the goal of permanent storage).
- In situ liability: the liability associated with leakage and/or migration of CO_2 from storage reservoirs that could damage public health impacts or the environment.

Operational liability issues are similar to current, well-managed issues in the oil and gas industries and should therefore not raise any particular problems. Climate liability will largely be dealt with under the accounting rules of any applicable climate change regimes (IEA GHG, 2004). The fact that there is a possibility of non-permanence makes it necessary to incorporate liability for future releases into accounting schemes (Bode *et al*, 2005). Perhaps even more complex will be the inclusion of CCS in emissions trading schemes, such as the European Union Emissions Trading Schem (EU ETS). Zakkour *et al* (2005) suggest that, although the EU ETS is based upon emissions only within installation boundaries, fugitive emissions should be reconciled across the CCS chain up to and including the point of injection (i.e. outside the installation boundaries). They are of the opinion that any liability for leakage from storage should be handled through States' licensing and permitting regimes because storage involves longer timescales and different regimes to those in the EU ETS.

The legal issues considered by the literature primarily relate to in situ liability, which is particularly challenging given the relatively long time frame of carbon storage. It is generally accepted that there should be continuous existence of a liable entity, however the issue lies in whether the entity with long-term liability should be public or private (IEA, 2005). Another potential issue is the need for joint liability where several operators are injecting into the same formation (Wall *et al*, 2004).

Several aspects of in situ liability will fall within the scope of the Directive on Environmental Liability (2004/35/EC), which was adopted in 2004 and must be implemented by Member States before April 2007. The Directive is aimed at the prevention of damage to habitats and protected species, damage to water resources and land contamination which presents a threat to human health. It does not cover economic loss, personal injury or property damage. In respect of damage to land, water or biodiversity caused by 'dangerous activities', strict liability will apply. The IEA GHG (2004) suggests that CCS would fall within the ambit of 'dangerous activities'. For biodiversity damage caused by non-dangerous activities, liability will be fault based. Under the Directive, it is the person or entity exercising control over an activity that attracts liability.

It is important to bear in mind that the Directive is not specifically targeted at CCS. As such, it does not appear to provide sufficient certainty in relation to the unique issues posed by CCS.

2.2.3 Relevant EU Directives

It is the general consensus that EU Directives impose no prohibitions *per se* on CCS activities. They do, however, impose requirements that may need to be satisfied (IEA GHG, 2003). These requirements will typically involve environmental impact assessments and/or permitting, which are covered in the regulatory issues section. The main directives which could have an impact on CCS are those on water (2000/60/EC), waste (75/442/EEC), landfill (1999/31/EC), pollution (1996/61/EC) environmental impact assessment (85/337/EEC) and strategic environmental assessment (2001/42/EC). These directives were created without consideration of CCS. Their applicability to CCS will therefore be determined separately by each EU Member State on the basis of their various implementation instruments (IEA, 2005).

2.3 Summary

The main issues arising in a public international law context relate to the international marine treaties. There is significant room for interpretation and clarification under these treaties, with several questions posed by the literature, including:

- Is storage in the sub-seabed covered by the treaties or is it limited to the water column?
- Does CO_2 storage constitute 'dumping' under the treaties?
- Does the process of CO_2 storage constitute 'pollution' under UNCLOS?
- Is CO_2 an 'industrial waste' under the London Convention?
- How, and to what extent, does the precautionary principle affect CCS?

Elucidation is also required under EU domestic law, with a focus on:

- The nature of property rights in sequestered gases, the storage reservoir and the surrounding land/seabed.
- Legal options for liability of private actors and States, particularly in light of the long time frame associated with CCS.

Permitting and assessment requirements are likely to be imposed by existing EU Directives, however they do not appear to represent a barrier to CCS development.

3. Regulatory issues

ACCSEPT has the legal and regulatory situation of CO_2 capture and storage as two of its four main elements. To clarify the distinction: Chapter 2 on legal issues covers aspects of obviously or potentially relevant public international law (the OSPAR Convention, the Basel Convention, the UNFCCC) and European and domestic law, particularly with respect to property rights, liability, and environmental planning and development law. This regulatory chapter addresses:
1. Inclusion of CCS in the climate policy context at different levels.
2. Permitting, assessments and guidance for capture, transport and (in particular) storage.

3.1 Inclusion of CCS in the climate policy context

3.1.1 International level

As CCS is an emerging option for greenhouse gas mitigation, CCS-related policy is still largely undeveloped. At the international level, the United Nations Framework Convention on Climate Change (UNFCCC) mentions the 'sustainable management…conservation and enhancement of sinks and reservoirs of all greenhouse gases' (Article 1d); Annex I Parties are further obliged to enhance 'greenhouse gas sinks and reservoirs' (Article 2a) The Kyoto Protocol, meanwhile, mentions the requirement for 'research on, and promotion, development and increased use of…carbon dioxide sequestration technologies' (Article 2.1).

The relevance to CCS of these initial mentions of 'sequestration' at UN level is uncertain: although some would argue that these most certainly refer to sequestration in terrestrial sinks such as forestry and agriculture, others regard the mention of 'technologies' as a clear reference to CCS, especially taking into account that at the time of the agreement of the Kyoto Protocol, publications on CCS had been published already, and the Sleipner project in Norway was already ongoing. In the Marrakech Accords, clear mention is made of CCS. The text 'Encourages nations to cooperate in the development, diffusion and transfer of less greenhouse gas-emitting advanced fossil-fuel technologies, and/or technologies relating to fossil fuels, that capture and store greenhouse gases…' Interestingly, this text is included three times, each in the context of 'minimizing the impact of response measures' - an issue one can characterize as primarily an OPEC attempt for recognition of their future loss of income if society moves away from fossil carbonaceous fuels.

Publication of the IPCC Special Report on CCS in 2005 formed the backdrop to discussion of CCS at the subsidiary bodies meeting during the COP11/MOP1 in Montreal. That meeting decided to hold a workshop on the issue at the subsequent meeting in May 2006. There will be sessions both on CCS generally, and in the context of the Clean Development Mechanism (CDM).

The CDM neither restricts nor encourages CCS: it must be evaluated as any other mitigation approach. The CDM has evolved as a precedent-based system, where project activities are based on methodologies that are evaluated and approved by the CDM Executive Board (EB) as they come in from project developers - subsequent projects can then make use of a developed and approved methodology. Hence there is a very high burden on first movers. Currently there are two CDM methodologies proposed. However, recognising the need for more expertise on the issue, the CDM EB asked its methodologies panel both to review those methodologies and to explore the issue further, and will convene a workshop on the issue in May at the SBSTA meeting.

CDM is a system with its own rules and logic, meaning CCS has the challenge of not only overcoming the barriers inherent to a new technology, but must find a way of fitting into the requirements of the CDM. A range of issues are probably going to come under considerations. First and foremost is how to guarantee proper site selection, which is the primary determinant of safe and effective storage - there are some rules of thumb, but no universally accepted guidebook as yet. Also important is to know where the 'project boundary' is drawn: if CO_2 storage is done as part of an enhanced oil recovery project, is the incremental oil production that is then combusted, releasing CO_2, somehow part of the equation? In terms of time spans, while CDM projects are only credited for ten years fixed, or seven years renewable twice, how does one account for potential leakage from the storage site in the long term? And how does one guarantee available funding to remediate any eventual problems? These and other issues will all need to be addressed. The revision of the IPCC accounting guidelines, expected this year, may go some distance to resolving these issues. However, these are guidelines for preparing national inventories reflecting the combined effect of classes of emitting activities, not guidelines for preparing projects; they also are there to assess what is present in a country, thus they will be helpful about required monitoring, but would not offer advice on site selection. In general the guidelines often supply rules of thumb and factors that may be too general to apply to specific projects.

There are other international initiatives that do not have the same reach as the UNFCCC or Kyoto Protocol, but nonetheless are emerging as important in the context of CCS. The Carbon Sequestration Leadership Forum (CSLF) is a grouping of 21 countries (including the European Community and several individual European countries) interested in furthering research and development, international collaboration and understanding of policy and regulatory aspects of CCS. While it recognizes projects, it is not as such a project development entity and its role and influence are still best described as under development. Other initiatives such as the recent bilateral agreement between the EU and China to develop a CCS project together are meant to further international cooperation between countries important to future climate change agreements as much as they are meant to make technological progress.

3.1.2 EU level

While there are several pieces of legislation that will certainly affect CCS development (such as Directives on water and waste, as noted in Chapter 2, CCS policy as such is almost nonexistent, but is under development.

EU involvement in CCS has primarily taken the form of technology research, through the Fifth and Sixth framework programmes administered by the Directorate General for Research of the European Commission[3]. However, there is growing recognition that the policy context must be developed to both facilitate and have influence over the nature of CCS deployment. Inclusion of a working group on CCS in the second phase of the European Climate Change Programme is an indication of this interest[4]. It is contributing to the Commission's thinking as it prepares legislation on CCS, the form and goals of which are as yet undefined. It will most likely attempt to harmonise certain regulatory aspects to ensuring high quality storage, including adequate site selection, monitoring and post-closure management.

The EU Emissions Trading Scheme (EU ETS) is the primary means of limiting emissions from large point sources of CO_2 in the EU, but CCS is as yet not an included activity. Section 4.2.2.1.3 of the Monitoring and Reporting Guidelines (Decision C(2004) 130) invites Member States to submit research to assist the Commission in developing guidelines for CCS projects, but also allows them to propose interim guidelines that, given Commission approval, would allow CCS to be an accepted activity in that Member State. The UK has gone some distance towards the development of such guidelines through the Department of Trade and Industry's sup-

3 See http://www.cordis.lu/sustdev/energy/ml-term/home.html.
4 See http://forum.europa.eu.int/Public/irc/env/eccp_2/library?l=/geological_storage&vm=detailed&sb=Title.

port of a research project (Zakkour and Haefili, 2004) and advisory process (the 'ad hoc working group on CCS in the CDM). However, the Commission has indicated its discomfort with approving even interim guidelines until a number of issues are discussed and resolved - most notably related to storage site identification and management.

3.1.3 Member State level

A review of European state-level policies (Solsbery *et al,* 2004) indicates that there are no developed policy frameworks as such in Europe, though in some cases there is a developing understanding of the way in which current regulatory regimes can apply or be extended to CCS. Further, the development of demonstration projects, and plans for commercial facilities, is picking up pace in several countries, testing the appropriateness of regulatory frameworks and pushing the issue forward.

The Netherlands issued a white paper in September of 2003 that mentions CCS as an option to be developed. The 2005 Energy Report gives it fuller consideration, placing it as a major 'transitional' option to clean energy production, third in order of priority after energy savings and renewable energy. In 2007 rules will be published that will make CCS eligible for certain clean energy subsidies from 2008[5].

The United Kingdom published its revised climate change programme in March, 2006[6]. In it, it noted several times that CCS is an emerging option for which financial support and regulatory framework will be developed, primarily through the ongoing energy review.

CCS is high on the agenda in Norway. The country has had a leading position through experience with the Sleipner project, and plans further projects and research. But politically the main issue is that as a hydropower-dominated country, any gas-fired power, no matter how efficient, is seen as an undesirable new source of carbon, and a threat to meeting its Kyoto target. Hence the government's resolution only to install new natural gas power plants if accompanied by CCS.

While Germany has not yet issued a government policy on CCS, it is recognised as an important issue, especially given the anticipated nuclear phase out. There is support for R&D activities, and progress, with influence on the policy situation, is to be evaluated in 2006 (CSLF doc). Other countries are similarly positioned, such as France and Denmark, hosting or planning demonstration projects, with information from them being influential in future policy planning.

Other heavy coal users and fossil-fuel dependent economies like Italy, Spain and Poland are participating in research and demonstration projects, though policy is under development. As one of the world's prime locations of natural CO_2 leakage, strategies for protecting the public, flora and fauna already developed in Italy have potential to facilitate preparations for CCS.

3.2 Permitting, assessments, and guidance

Industrial activities have to be permitted; those permits are frequently the focal point for applying relevant regulations - conditions of the permit will reflect requirements and spell out what is expected of the facility. Thus while there is some existing regulation relevant to CCS in various countries, and some new specific regulations are under development, it is the permitting process

5 Speech by State Secretary Van Geel at the national symposium 'Clean Fossil' at the Museon in Den Haag on 23 November 2005.

6 United Kingdom, Department of Trade and Industry, Energy Review, ongoing. http://www.dti.gov.uk/energy/review/. The public consultation finished April 14th, 2006, but the review is still underway.

that focuses these disparate efforts into a coherent process, and hence is a major leverage point for the discussion.

CCS has three main components, each of which will be permitted differently, as they are different locations and types of activity: capture, transport and injection/storage. These in turn will each have three major milestones in their life cycles: planning, operation and decommissioning[7]. In the case of storage, there will also be a long-term stewardship component.

Each element will affect current permitting regimes, or require new thinking beyond current regulations. Under CO_2 capture, for example, the energy penalty means reduced efficiency, which affects Best Available Technology efficiency requirements under the Integrated Pollution Prevention and Control Directive (IPPC) and requires a separate assessment to justify the increased total benefit[8]. With transport there are fewer new considerations, except to consider the properties of CO_2: while not flammable it is heavier than air and an asphyxiant - different properties to, for example, natural gas. Further, it must be transported dry to avoid corrosion of infrastructure.

The main issue, however, is geological storage. A range of permitting issues comes in at different stages of development, as below. Below that is a list of the range of activities in project development, which would need to be reflected in a permit.

Site selection/planning:
    Permission to prospect for storage sites.
    Planning permit for the site based on appropriateness of site characteristics.
Site development
    Permit for injection facility development based on safe and efficient operation.
Operational phase
    Permit for continues operation based on reservoir performance.
Site decommissioning
    Permit conditions for site sealing and decommissioning.
Site Stewardship
    Permit conditions for ongoing monitoring.

Permissions and permits can be in the context of environmental impacts assessments, as required under the EU EIA Directive, but overlaid by differing requirements as each step of the CCS chain may fall under different pieces of legislation.

[7] ERM, IEA GHG technical study 2006/3: provides a comprehensive overview of permitting.
[8] ERM, ibid.

4. Are we making economic sense of CCS?

The economics of CCS are often discussed in terms of mitigation costs - how much it costs to avoid a tonne of carbon dioxide entering the atmosphere. Policymaking for implementation of CCS, however, also requires taking into account other aspects of the economics besides those related to the carbon price. The full economic picture therefore also includes how much CCS would increase the cost of electricity, compared to current prices and the costs of other mitigation options, and how the costs can be divided into initial investment and operational costs. This section reviews some of these economic aspects of CCS and arrives at some conclusions that might be relevant for CCS acceptance.

4.1 In general: costs of CCS

The IPCC Special Report on Carbon dioxide Capture and Storage summarises the costs of CCS in two ways: in terms of additional costs per kWh (for the electricity sector), which concentrate in the range of 0.02 to 0.03 US$/kWh. It also assesses the costs in terms of climate change mitigation cost, in US$ per tonne of CO_2 avoided. These costs are summarised in Table 4.1.

Table 4.1 *CO_2 avoidance costs for the complete CCS system for electricity generation, for different combinations of reference power plants without CCS and power plants with CCS*

Type of power plant with CCS	Natural Gas Combined Cycle reference plant [US$/t$CO_2$ avoided]	Pulverized Coal reference plant [US$/t$CO_2$ avoided]
Power plant with capture and geological storage		
Natural Gas Combined Cycle	40-90	20-60
Pulverized Coal	70-270	30-70
Integrated Gasification Combined Cycle	40-220	20-70

Note: Costs of Enhanced Oil Recovery instead of normal geological storage can be obtained by subtracting 20 to 30 US$/t$CO_2$.

4.2 Mitigation costs

Economic estimates for the mitigation costs of CO_2 capture and storage have been floating around for the last fifteen years. Engineering costs are generally estimated at the plant level. If the technology has already been implemented, those costs are based on the installation and the operation and maintenance costs of those existing plants. If the technology is new, costs of comparable technologies can be used to estimate the costs[9]. Bottom-up cost information may serve as an input for top-down economic models. In such least-cost optimisations of the mitigation portfolio under stabilisation scenarios, CCS is taken as one of the options for reduction of emissions. Costs are expressed in a cost curve, which relates the costs of reducing emissions to the overall potential for emission reduction of the option[10]. Such a cost curve aggregates all CCS options into one curve. The low-cost options for CCS, such as ammonia plants and natural gas processing facilities combined with low transport costs and a geological storage option that allows for enhanced hydrocarbon production, amount to a potential of around 360 MtCO_2 per year (IPCC, 2005). However, this number is very uncertain. Early opportunities may be determining the extent to which CCS may take off in the coming decade, and good information, pos-

[9] See e.g. Section 8.2 of IPCC (2005), as well as numerous references in Rubin *et al.* (2005).
[10] See e.g. Section 8.3 of IPCC (2005), IEA (2004).

sibly world-wide, might help decision-makers tremendously in choosing the appropriate policies to support CCS.

Estimates of costs for CCS have uncertainties, especially for new technologies. If there is no actual experience with a full-scale CCS project, it is hard to estimate the costs. It contributes to the uncertainty that experience - and therefore cost certainty - is smallest in the most expensive component of the system: the full-scale application of capture. Also, the engineering costs tend to look only at the application of CCS to a distinct type of power plant. In real life, instead of investing in e.g. a coal plant with post-combustion capture, a gas plant with capture or even renewable energy could be considered. But generally speaking, because of the detailed nature of bottom-up costs, and the estimates that can be made based on comparable operations, these costs are estimated as rather reliable.

The estimates resulting from bottom-up engineer information should be in the same range as the cost input data for top-down models. It is, however, unclear whether that is indeed the case, as is shown by the following analysis. Input values for the costs CCS in top-down models can be deducted from a comparison of model results in terms of CCS deployment on the one hand and the associated CO_2 prices on the other. The IPCC (2005) compares two models - the European MESSAGE and the American MiniCAM model. Both use the same baseline (B2) and stabilisation level (550 ppmv). The deployment level of the MESSAGE model in 2020, at a carbon price of about 8 US$/t$CO_2$ is zero, and in 2035, when the price is 11 US$/t$CO_2$, about 300 Mt$CO_2$ per year. In the MiniCAM model[11], at a marginal carbon price of only 2 US$/t$CO_2$ in 2020, there are deployment levels up to about 1500 MtCO_2 per year. In 2035, CO_2 reduction prices rise to 11 US$/t$CO_2$, and deployment even reaches over 3 GtCO_2 per year[12]. This is summarised in Table 4.2. Part of the large deployment may be due to the 'perfect foresight' in the models - the model knows in 2020 that the price in 2035 will be higher. Obviously, this is not the case in the real world, where uncertainties about future climate regimes and price developments prevail. But even taking 'prefect foresight' into account, the deployment in the MiniCAM model in 2020 is large compared to the engineering costs.

Significant deployment of CCS at relatively low carbon prices (i.e. under 8-11 US$/t$CO_2$ for MESSAGE and under 2-11 US$/t$CO_2$ for MiniCAM) are not in line with the considerably higher bottom-up cost estimates. Thus, there is a discrepancy between available bottom-up cost estimates, and the seemingly low input cost data for CCS in top-down models. The projection, resulting from these models, that CCS plays a large role in the climate change mitigation portfolio should therefore be regarded with care, and policymakers should be made more aware of the underlying assumptions on the costs.

Table 4.2 *Comparison of CCS deployment in MESSAGE and MiniCAM*

Year		MESSAGE	MiniCAM
2020	Marginal carbon price [US$/t$CO_2$]	8	2
	CCS deployment [GtCO_2/yr]	-	1.5
2035	Marginal carbon price [US$/t$CO_2$]	11	11
	CCS deployment [GtCO_2/yr]	0.3	3

Note: Derived from data in IPCC (2005).

11 See Brenkert *et al.* (2003): Model documentation for the MiniCAM. Exact cost data could not be retrieved for the MiniCAM.

12 Current CO_2 prices vary much. In the EU Emissions Trading Scheme, prices around 30 US$/t$CO_2$-eq are reported. In projects for the Clean Development Mechanism, prices are more around 5 to 10 US$/t$CO_2$-eq. In the voluntary United States Chicago Climate Exchange, prices are between 1 and 2 US$/t$CO_2$-eq.

4.3 Incremental electricity costs

The cost of the product of the installation to which CCS is applied will increase as a result of the add-on of the capture technology. The estimates of additional costs for commodities outside of the electricity sector, such as in the steel, the fertiliser or in the cement industry, are often not available, unless for cheap options such as in the gas processing industry or in the ammonia industry. Costs of natural gas processing, for instance, are proportional to the amount of CO_2 in the natural gas stream. In that case, high concentrations of CO_2, like at the Natuna gas field off the coast of Indonesia, imply high cost of capture (although the capture needs to be done anyway). Offshore gas fields will also have more expensive installations to capture CO_2 than onshore.

The incremental electricity costs are likely to converge in a range of 0.02 to 0.03 US$/kWh (IPCC, 2005), based on an engineering costs analysis and assuming large-scale deployment. The acceptance of such costs may depend strongly on base price of electricity, which can be very different in different countries and regions. For instance, household electricity prices in Germany are about 0.20 US$/kWh[13], and an increase of 10 to 15% will not contribute to a drastic increase of consumer's expenditures on electricity. In the United States, however, the household electricity prices are lower: about 0.09 US$/kWh[4]. CCS application would then increase prices by about 20 to 35%, which might lead to resistance. In several European countries, household electricity prices are even higher than in Germany, and in Canada and Norway, prices are lower than those in the United States. For industry, which pays significantly less for electricity than households (0.08 US$/kWh in Germany, and 0.05 US$/kWh in the Unites States), CCS could even increase prices by 25 to 60%. These relative price changes may affect the acceptability of CCS to both the general public and the private sector.

4.4 Costs differentiation

If companies make an investment decision, it is influenced by the distribution of costs. If the upfront investment costs are high, the developer both must commit more capital, which comes at a cost, and also faces a higher risk with that capital. The electricity sector, being a regulated sector, is risk-averse in nature, and will dislike high upfront capital costs. The fossil fuel industry, in contrast, is more risk seeking, and currently has higher profit margins, despite being very capital-intensive.

A survey among European models in the CASCADE-MINTS project[14] yielded results that varied significantly over the models. For instance, for an integrated gasification combined cycle power plant with CO_2 capture, estimates of the current investment costs varied from ca. 800 to 2100 €/kW among the different models, corresponding to an average deviation of 21%. The variance of operational costs is less pronounced. For gas-based plants, the investment costs are generally lower and vary from 600 - 1150 €/kW. IPCC (2005) gives smaller ranges for investment costs: 1169-1565 US$/kW for IGCC with capture, and 515-724 US$/kW for natural gas with capture. The increase in investment costs as a consequence of CO_2 capture is on the order of 30% for coal-based IGCC, but up to 100% for gas-fired plants. For gas, in addition to the rise in investment costs, also supply security arguments may plead against its use, also with CCS. As this may influence corporate decisions, it is important for any policy incentive to be put in place to respond to the specific cost characteristics of the mitigation option.

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13 IEA Key World Energy Statistics 2005, page 43.
14 See http://www.e3mlab.ntua.gr/cascade.html for more information on the CASCADE-MINTS project.

4.5 Main messages

1. It seems that several highly influential, aggregate planning and decision support models use low values for the costs of CCS, which might result in an overestimation of the role of CCS in the mitigation portfolio. The extent to which this also applies to other models is unclear, as the cost input data are not public.
2. Since electricity prices differ worldwide, the relative increase of the electricity price following large-scale application of CCS (as well as other mitigation options) will differ around the globe. As a consequence, the public in regions with low electricity prices might be more reluctant to accept CCS (or other mitigation options) than elsewhere.
3. For a realistic assessment of the role of CCS in climate change mitigation the differentiation of costs must be taken into account, as the details of corporate decision-making depend on the cost distribution between upfront investment costs operational costs, as well as on the nature of the sector.
4. More insight in early opportunities for CCS, in industrialised but also in developing countries, would be helpful in designing policy support for CCS in such a way that it can develop in an optimal way.

5. Social and public acceptability

Public perceptions can have a very significant, and frequently unanticipated, effect upon major planned projects involving new technologies and infrastructure. Examples include: the effects of public opinion on the planned disposal of the Brent Spar oil platform in the mid-1990s, and the on-going debates over genetically modified organisms (GMOs), and nuclear and other hazardous waste disposal (Smith 2000, Irwin & Michael 2003, Hunt & Wynne 2000). Closer to the issue of CO_2 storage, proposals for underground natural gas storage schemes have generated public opposition in some localities, despite similar facilities operating very close by (and in other countries) with out apparent concern (Gough *et al,* 2002). In two such cases, concerns about uncertain and difficult to assess risks to health and safety emerged. The effect that such perceived risks could have on local property prices also caused concern. The local media played an active role in disseminating the concerns about these natural gas storage proposals to a wider public audience (Overwyrefocus, Nogasplant websites, no date). Other potential analogs for assessing the acceptability of CCS include Liquid Petroleum Gas storage and the Underground Injection Control Program in the USA because of similarities in the legal and regulatory regime (Wilson *et al*, 2003, Reiner & Herzog, 2004). It may be such experiences that led a representative from BP to comment recently that public opposition could be a potential showstopper in the implementation of CCS (HoC 2006).

Indeed, the importance of public acceptance has been expressed at the highest levels, including as part of the Gleneagles Plan of Action from the 2005 G8 Summit (G8, 2005). In the written submissions to the recent UK House of Commons Science and Technology Committee Inquiry on Carbon Capture and Storage Technologies, no less than ten submissions explicitly referred to public acceptance as being a top priority. Groups as diverse as the British Geological Survey ('without public acceptance there will be no CO_2 storage'), Air Products ('Safety and public acceptability for the whole system are of paramount importance'), the Royal Society of Chemistry ('Although a number of technical issues dealing with storage safety, monitoring and longevity are still outstanding, the public acceptance of geological storage is probably the overriding issue') and Rio Tinto ('the immediate priority is to accelerate the development and deployment of CCS and to gain wider public acceptance for CCS'). Of course, in spite of such seemingly universal appreciation for the importance of public acceptability, the actual empirical evidence is rather slight.

The social acceptability of CCS includes the responses of the lay public and of 'stakeholders' - defined here as agents which have a professional interest in CO_2 capture and storage through employment or personal engagement in a voluntary capacity. Hence, stakeholders can include industry, industry associations, environmental and other non-governmental organisations, governmental and research organisations. The issues are quite different for the lay public and stakeholders because the latter nearly always have a defined agenda or set of preferred policy objectives in mind when evaluating CCS, whereas the lay public cannot be expected to hold an *a priori* viewpoint. Zaller (1992) argues that the lay public does not have well formed opinions on most issues which are not of immediate salience or relevance to their everyday life and livelihood. Opinions and perceptions are, instead, shaped by the media and other marketing efforts of stakeholders. Wynne (1996) notes that, bereft of sufficient technical knowledge, the public may come to rely upon their sense of trust in the organisations involved, and in their past institutional performance, when assessing CCS (see also Huijts, 2004). Hence, we will consider acceptability to the public and stakeholders separately (though much less has been written about the latter).

5.1 Lay public perceptions

There are a few empirical studies of public perceptions of CCS, with four separate studies having been reported in the EU region (two in the UK, two in the Netherlands). Further studies of public perceptions have been reported in the USA, Canada, Japan and Australia. Table 5.1 summarises the different studies to date. One of the few actual experiences of public perceptions is the Ocean Field Experiment in Hawaii, a case-study of which has illustrated how bureaucratic obstacles, a few dedicated activists and slow recognition of the need for public outreach derailed the project (de Figueiredo, 2002).

Table 5.1 *Summary of public perception studies*

Country	Sample Size and Survey Instrument	Organisation(s) and Dates Conducted
Australia	900 computer assisted telephone interviews in Queensland area (300 in Brisbane) plus 95 stakeholder interviews	CSIRO/ University of Queensland (6/2005)
Canada	1972 out of 8500 (23%) using internet survey with 40% in Saskatchewan and Alberta plus two focus groups	Simon Fraser University (12/2004-3/2005)
Japan	Written questionnaire, 1,006 responses, response rate of 63.9% survey of representative sample in the Tokyo and Sapporo metropolitan areas	Fuji Research Institute (with AIST) (12/2003)
Netherlands	995 respondents for Information-Choice Questionnaire and 327 and 300 in two traditional questionnaires	CATO/Leiden University (10-11/2004)
Netherlands	112 face-to-face interviews with residents in areas of natural gas storage (58% acceptance rate)	Eindhoven University of Technology (5/2003)
Sweden	Written questionnaire, national sample of 589 respondents out of 1,500 (39%)	Chalmers University of Technology/ SCB (Statistics Sweden) (12/2004)
UK	Internet-based, national sample of 1,056 respondents out of 2,640 (40%) in Great Britain	Cambridge/MIT/YouGov (8/2004)
UK	212 face-to-face interviews at Liverpool Airport (40-50% acceptance rate) plus two citizen panels	Tyndall Centre (8/2003)
US	Internet-based, national sample of 1,205 respondents out of 1,710 (70%)	MIT/Knowledge Networks (10/2003)
US	126 closed-form written questionnaires for convenience sample in Pittsburgh, Pennsylvania area	Carnegie-Mellon University (2003)

Curry *et al* (2005) found that less than 4% of US respondents were familiar with the terms carbon dioxide capture and storage or carbon sequestration. Moreover, there was no evidence that those who expressed familiarity were any more likely to correctly identify that the problem being addressed was global warming rather than water pollution or toxic waste. They also showed that there was a lack of knowledge of other power generation technologies (e.g. nuclear power, renewables) in terms of their environmental impacts and costs. (Eurobarometer 2003 made similar findings across the European Union). The preference of the sample for different methods to address global warming (do nothing, expand nuclear power, continue to use fossil fuels with CO_2 capture and storage, expand renewables, etc.) was quite sensitive to the information provided on relative costs and environmental characteristics.

Shackley *et al* (2005) found that the sample was, in general, moderately supportive of the concept of CCS (here limited to offshore geological storage) as a contribution to a 60% reduction in CO_2 emissions in the UK by 2050 (the government's policy target). Provision of basic information on CCS increased the support that was given to it, though just under half of the sample were still undecided or expressed negative views. When compared with other mitigation options, support for CCS increased slightly though other options such as renewable energy and energy efficiency were much more strongly preferred. On the other hand, CCS was much preferred to nuclear power or higher energy bills (though no information on price or environmental impacts of the other options was provided). When asked, unprompted, if they could think of any negative effects of CCS, half of the respondents' mentioned leakage, whilst others mentioned associated potential impacts upon ecosystems and human health. Others viewed CCS negatively on the grounds that it was avoiding the real problem, was short-termist, or indicated a reluctance to change.

Curry *et al* (2005) have also conducted a survey of public attitudes towards energy and the environment in the UK through YouGov, an online polling company. A number of questions concerned perceptions of a range of carbon mitigation options including CCS. The findings are broadly in agreement with Shackley *et al* (2005). Over 70 per cent of respondents believed that action needs to be taken to address global warming and the majority of that group thought that immediate action is necessary. Very few respondents had previously heard of CCS. There was a strong preference for renewable energy technologies as a way of tackling global warming, with 80 to 90 per cent of the sample in support. Curry *et al* (2005a) identified somewhat lower support for CCS (at c. 30 per cent) than Shackley *et al* (c. 50%), though in both surveys about 20 per cent of the sample was opposed to use of CCS. Curry *et al* (2005a) also identified somewhat greater support for nuclear power than in Shackley *et al* (at c. 35 per cent in favour compared to c. 25 per cent) and less negative opinion towards nuclear (at c. 30 per cent compared to c. 55 per cent against). Curry *et al* also explored the difference that provision of information on potential costs of different options made to the respondents' perceptions of the alternative mitigation options. There was, in response to this further information, a relatively small shift towards support for nuclear and CCS and away from renewables. What is striking is the similarity of Curry *et al*'s conclusion that: 'Carbon capture and storage …. received a slightly net favourable response, whereas nuclear energy and iron fertilisation were viewed more negatively' (2005a:14), and the conclusions of Shackley *et al* (2005).

Itaoka *et al* (2004) found much higher claimed levels of awareness of CCS (31%) in Japan and general support for CCS as part of a broader national climate change policy, but generally negative views on specific implementation of CCS. Ocean storage was viewed most negatively, whilst offshore geological storage was perceived as the least negative. Part of the sample was provided with more information about CCS but this did not appear to make a large difference to the response. Factor analysis was conducted and revealed that four factors were important in influencing public opinion, namely perceptions of: the environmental impacts and risks (e.g. leakage); responsibility for reducing CO_2 emissions; the effectiveness of CCS as a mitigation option; and the extent to which CCS permits the continued use of fossil fuels.

Huijts (2003) found that the sample, which were living in an area located above a gas field in the Netherlands that had experienced two small earthquakes (in 1994 and 2001), was slightly positive about CCS in general terms, but neutral to negative about storage in the immediate vicinity of their neighbourhood. On the other hand, the respondents thought that the risks and drawbacks were somewhat larger than the benefits to the environment and society. The respondents considered that the personal benefits of CCS were ‘small’ or ‘reasonably small’. On the basis of her findings Huijts observed that the location of storage could make a large difference to its acceptability; onshore storage below residential areas would probably not be viewed positively, although it has to be borne in mind that the study area had experienced recent earthquakes. Huijts also notes that many respondents (25%) tended to choose a neutral answer to questions about CCS, suggesting that they did not yet have a well-formed opinion.

Ashworth *et al* (2005) analysis showed just over 70% of Australian respondents were unable to provide a correct answer to the open-ended question ‘Please tell me what you understand about carbon, capture and storage (CCS)?’ Nevertheless, a relatively substantial segment was able to provide a reasonable answer including: geosequestration (2%); collecting gas from generators (5%); putting gas underground (7%); storing gas in barrels (2%); and tree planting (6%). The vast majority (80%) was unaware of any efforts by the coal industry to reduce greenhouse gas emissions. Australians were, on average, favorably inclined toward CCS, compared to strong support for solar and wind power and strong opposition to introducing nuclear power. CSIRO also conducted a survey of some 95 members of the public in a series of workshops as well as several interviews with key stakeholders from industry and the environmental NGO community. The workshop participants recognized that the increase in energy demand would not be met by renewables alone in the near future and that there was a need for a portfolio of approaches (Pisarski *et al*, 2004). However, most participants also felt that, if used, CCS should only be seen as an interim strategy and that research into CCS should not come at the expense of renewables. There was also a sense that many in government were supporting the carbon capture and storage technology at too early a stage. Finally, participants expressed interest in being engaged on the issue of low emission technologies and their impact. It was thought particularly important to engage with Australian youth, as they will be most affected by the technology.

De Best-Waldhober and Daamen (2006) conducted surveys of ‘informed preferences’ for six possible CCS options and compared their results against more traditional public opinion survey results for those same options. They found that, on average, the informed respondents rated all six options as ‘adequate’ (just over 6 on a scale of 1-10) with solid oxide fuel cells with CCS ranked highest and enhanced coalbed methane the lowest (but still acceptable). Depending on the CCS option, 12% to 24% ranked the technology very positively (ranked 8, 9 or 10) and only 4% to 6% ranked the technology options negatively (ranked 1, 2 or 3). By contrast, in two more traditional surveys of some 300 respondents conducted a year apart, the authors found the tendency for respondents to report ‘pseudo-opinions’, i.e., opinions that changed over the course of as little as 12 minutes if respondents were asked to do an irritating task in the interim. Opinions were found to be sensitive to the mood of the respondent and small amounts of extraneous information and were generally less supportive of all options than the better-informed respondents.

Sharp (2005) conducted two focus groups (in Edmonton and Toronto) in addition to a national internet-based survey across Canada. The results showed that a strong majority of Canadians believe that climate change is occurring and some action should be taken to address it. However, climate change was ranked very low in importance compared to other national issues, and was the lowest ranked environmental issue. Knowledge of CCS (described in this work as Geological disposal of carbon dioxide or GDC) was low - even among those claiming to have heard of the technology respondents could not correctly identify what environmental problem it was meant to address. They perceived the technology as having a net positive impact on the environment, and believed it to be less risky than conventional oil and gas operations, nuclear power, or coal-burning power plants. More than half of respondents would likely use GDC (CCS) in a climate change strategy, while only a quarter of respondents would likely not include it. However, GDC was much less popular than energy efficiency and renewable energy alternatives.

Palmgren *et al* (2004) found that provision of more information led the survey respondents to adopt a more negative view towards CCS. The study also found that when asked in terms of willingness to pay the respondents were less favourable towards CCS as a mitigation option that they were to all the other options provided (which were rated, in descending order: solar, hydro, wind, natural gas, energy efficiency, nuclear, biomass, geological disposal and ocean disposal). Ocean disposal was viewed more negatively than geological disposal, especially after information was provided.

Focus group research on CCS has been conducted in the UK in 2001 and 2003 (Gough *et al,* 2002, Shackley *et al,* 2005). Initial reactions to the concept of the geological storage of CO_2 tended to be sceptical and it is only within the context of the broader discussion of climate change, and the need for large cuts in carbon dioxide emissions, that opinions become more receptive. Typically, participants of these groups were clear that other approaches such as energy efficiency and demand reduction measures and renewable energy should be pursued as a priority and that geological CO_2 storage should be developed alongside, and not as a straight alternative, to these other options. There was general support for the use of CCS as a 'bridging measure', whilst other zero- or low-carbon energy technologies are developed, or as an emergency stop-gap option if such technologies are not developed in time. There was a moderate level of scepticism amongst the participants towards both the government and industry and what may motivate their promotion of CO_2 storage, but there was also some distrust of messages promoted by environmental groups. Levels of trust in key institutions and the role of the media were perceived to have a major influence on how CCS will be received by the public, a point also made by Huijts (2004).

The existing research described above has applied different methodologies, research designs and terminology, making a direct comparison impossible. Inconsistencies in the results have arisen concerning, e.g. the effect of providing more detailed information to respondents, the evaluation of CCS in general terms and in comparison with other low-carbon mitigation options. Explanations for these differences might include the extent of concern expressed regarding future climate change. Representative samples in the US and EU (Curry *et al,* 2005, Eurobarometer 2003) and most of the smaller samples (Shackley *et al,* 2005, Itaoka *et al,* 2004) find moderate to high levels of concern over climate change, whereas respondents in the Palmgren *et al* study rated climate change as the least of their environmental concerns. A further explanation of the difference in perceptions might be the extent to which perceptions of onshore and offshore geological storage have been distinguished in the research.

From this highly limited research, it appears possible that at least two conditions may have to be met before the CCS option is considered by the public as a credible option alongside other better known options: a) anthropogenic global climate change has to be regarded as a relatively serious problem; b) acceptance of the need for large reductions in CO_2 emissions to reduce the threat of global climate change. When these two statements are accepted, CCS may then come to be regarded as one of the range of major mitigation options. As noted above, many existing surveys have indicated fairly widespread concern over the problem of global climate change, and a prevailing feeling that the negative impacts outweigh any positive effects (e.g. Kempton et. al., 1995, Poortinga and Pidgeon, 2003, Eurobarometer, 2003, Hargreaves *et al*, 2003, MORI 2004). On the other hand, some survey and focus group research suggests that widespread acceptance of the above two factors amongst the public, in particular the need for large reduction in CO_2 emissions (Hargreaves *et al*, 2003), is sporadic and heterogeneous within and between national populations (MORI 2004a, Lorenzoni, 2003, Sharp, 2005). Lack of knowledge and uncertainty regarding the economic and environmental characteristics of the other main mitigation options has also been identified as an impediment to the evaluation of the CCS option (Reiner *et al*, 2006, Curry *et al*, 2004).

Acceptance of the two conditions does not imply support for CCS; this may still be rejected as too 'end of pipe', treating the symptoms not the cause, delaying the point at which the decision to move away from the use of fossil fuels is taken, diverting attention from the development of renewable energy options and with potential long-term risks which are too difficult to assess with certainty. Acceptance of CCS, where it occurs, appears frequently to be 'reluctant' rather than 'enthusiastic', and in some cases reflects the perception that CO_2 capture and storage might be required because of failure to reduce CO_2 emissions in other ways. Furthermore, several of the studies above indicate that an 'in principle' acceptance of CCS can be very different from acceptance of storage at a specific site.

5.2 Role of other stakeholder groups and the media in shaping public perceptions

Feedbacks between the media and public opinion have been formalised in the theory of risk amplification (Jaeger *et al*, 2001), which maintains that risk perceptions can become amplified through media presentations, and subsequent stakeholder responses. The implication of such theory and real-cases is that public opinion on CCS could, at some future stage, be strongly shaped by stakeholder groups, including the media, who come to formulate a strong opinion. Research is not able to anticipate how public perceptions might change, possibly dramatically and rapidly, in response to pro-active stakeholder and media interventions and real-world events, though it can provide lessons from the past and guidance on 'good practice' in the communication of risks and uncertainty.

There have been only a small handful of studies to date on media portrayals of CCS. Bradbury and Dooley (2004) conducted their survey of local and national media coverage from mid-November 2002 through to the end of 2003 as part of The Ohio River Valley CO_2 Storage Project ('Mountaineer Project'). Of the 284 articles reviewed, more than 90% of articles on both the Mountaineer Project and on CCS more generally were classified as either positive or neutral. The most common source of information was the government (the US Department of Energy) followed by industry and then environmental groups. Coverage was often triggered by specific events such as the DOE announcement of the FutureGen project in February 2003 and the formation of the Carbon Sequestration Leadership Forum in June 2003.

Gough and Mander (2006) surveyed print media in five English-speaking countries between 1 September 2005 and 31 January 2006 to explore the impact of the publication of the IPCC Special Report on Carbon Capture and Storage at the end of September 2005. In Australia and the UK in particular, there has been increasing press coverage of CCS. Across the countries surveyed, more articles were positive or neutral towards the technology rather than negative or mixed. Positive aspects commonly cited include continued use of coal-fired generation without CO_2 emissions, energy security considerations including the potential to exploit domestic coal reserves and as an alternative to nuclear power. The most frequently cited negative attribute was its cost (particularly in Australia and the US) but also that the technology was considered to be 'unproven' or 'untested', as well as concerns over whether there was sufficient storage capacity worldwide as well as more technical concerns over safety, leakage, and the energy penalty associated with capture. A key issue highlighted by Gough and Mander was the urgent need for a framework to encourage investment in CCS technology.

5.3 Stakeholder perceptions

There are a large number of CCS policies, programmes and projects (PPPs) which include some form of stakeholder participation. Most national programmes in CCS now include some stakeholder liaison exercise alongside the R&D and various technical assessment activities underway, in particular those in EU countries, the USA, Australia and via international activities such as the Carbon Sequestration Leadership Forum. Most of these activities appear to consist of holding workshops where information is shared, comments and opinion are invited and a discussion between different parties is had. In some cases, there are moves towards more active involvement of stakeholders in the design of CCS PPPs, e.g. the regional CCS partnerships in the USA.

It should be recognised that some stakeholders are very much directly involved in the formulation and design of PPPs. Some large companies with a commercial interest in CCS, for example, are active in advising on the design and formulation of PPPs within national governments, the EU and other international organisations. As such they are also often active in enrolling other stakeholders to become involved in CCS related activities.

There have been very few independent studies of the involvement in, and perceptions, of stakeholders regarding CCS. Based on initial focus groups conducted in 2001, the CO_2 Capture Project (CCP) concluded that: 'NGOs in general have a negative outlook on the issue, as they believe that CO_2 storage will extend the usage of fossil fuels and divert resources from the development of renewable energy' (Lee *et al*, 2004). Scepticism is evident in a recent statement from the Climate Action Network Europe: 'Presently the discussion [on CCS] mainly works as a smoke screen for coal and lignite industries who desperately try to stay in business' (CAN-Europe 2006). On the other hand, the CCP argued that some NGOs were 'developing a more positive opinion on carbon capture and storage, realizing that a transition phase is likely to be needed before renewable energy can become more cost-effective and widely implemented.' and an enabler of the hydrogen economy.

Anderson (2005) has noted that NGOs engage in a 'continuous re-evaluation process ….to establish priorities: for some, climate technologies will fit into an important effort of the moment, for others it is far lower on the list' (7). Whilst long-term protection of the climate system is their ultimate objective, most NGOs focus on 'here and now' political discussions and developments, whereas CCS involves long-term technology development. Furthermore, NGOs may perceive that CCS is already being sufficiently promoted by industry and government to require or justify extensive additional support from the NGO community. There are other reasons why NGOs are frequently less than enthusiastic about (whilst generally not being overtly hostile to) CCS, e.g. the potential effects upon the development of renewables, energy efficiency and demand reduction activities, as well as potential adverse environmental impacts arising from leakage and continuation of coal mining (Anderson 2005). Where NGOs have mobilised around the CCS issue this has been the consequence of proposed ocean disposal experiments, to which all NGOs are opposed (Anderson 2005, de Figueiredo 2002). The other case of active NGO engagement has been in Australia, where scepticism to CCS has been high, perhaps due to Australia's decision not to sign the Kyoto Protocol and the importance of coal as an export industry.

In summary, the position of NGOs on CCS is presently rather contingent and hard to characterise with any degree of certainty. For example, some NGOs would be radically against CCS if it were clearly being developed at the expense of renewable energy, but mildly supportive if it were seen as an interim measure to help strong renewables development. As NGOs are tactical in nature, so principles tend to be broad, but specific positions are often quite reactive - one might find a generally supportive NGO being strongly against CCS in the EU ETS because there is at the same time, in their judgement, insufficient development of renewable energy technologies.

Shackley *et al* (forthcoming) and Gough *et al* (forthcoming) analysed stakeholder opinion of CCS as part of detailed regional case-studies of the potential implementation of CCS in the electricity sector over the next fifty years. Both case-studies used multi-criteria assessment and revealed a large disparity of opinion even amongst small samples of regional stakeholders who are knowledgeable about energy issues. Opinion was especially divided over the Fossilwise, Nuclear Renaissance and Renewable Generation scenarios in both regions. CCS as a key element of the Fossilwise scenario scored well with respect to the criteria of costs, infrastructure, reliability, security, public opposition and resilience to disasters. It did less well with respect to the criteria of environmental impacts and lock-in.

5.4 Comparison with other carbon abatement technologies

It may be useful to compare perceptions of CCS by stakeholders and the public with their perceptions of other energy technologies, in particular ones which offer a low- or zero-carbon generation route. This is useful not only in terms of such existing technologies providing an analogue, but also because CCS might well end up competing with some of these alternative options for industrial and public policy support. A prime alternative to CCS is nuclear power and so a focused comparison of perceptions of nuclear in different national settings may be helpful. Grove-White *et al* (2006) have argued that any shift in favour of nuclear power in the UK context would be highly conditional on the political, industrial and institutional framework in which nuclear were to be developed. Based upon an analysis of the development of the nuclear industry in the UK from the 1950s to the late 1980s, Grove-White *et al* point to the unusually centralizing, inflexible and security-sensitive character of nuclear energy technology. For example, the highly complex and extended nuclear fuel cycle required long-term and expensive commitment from Government, whilst the possibility of catastrophic accidents led to unique and privileged liability terms. Particularly onerous security arrangements were required because of the properties of radioactive materials. The notion of 'series ordering' of power plants to achieve economies of scale was promoted in 1973 and 1979, but if accepted, would have reduced the flexibility available to policy makers to modify policy decisions as circumstances changed. Grove-White *et al* (2006) point to the tendency of the nuclear industry and its advocates to attempt to re-create these centralizing and inflexible properties of a new nuclear build programme, e.g. through proposed changes to the land use planning system, streamlining of generic licensing procedures for new reactor designs and guaranteed series-ordering of nuclear plants. They conclude that such advocacy by the nuclear industry could back-fire because such proposals could readily ignite opposition from a wide range of influential public and policy constituencies based upon the perceived undesirability of highly centralized inflexible technologies. Grove-White *et al* do not argue that a new nuclear programme is entirely infeasible, however. Rather:

Greatly increased openness and transparency about the economics of the industry, a convincing long-term solution to the nuclear waste issue, and the adoption of manifestly 'fail-safe' new reactor types without the associations of past ventures … could conceivably alter the picture to bring about shifts in public responsiveness. (Grove-White *et al*, 2006, p.12).

An interesting question of ACCSEPT is the extent to which these observations might or might not apply to the case of CCS.

6. Cross-cutting issues related to CCS

The relative attractiveness and acceptability of CCS will be greatly strengthened when it is economically predictable and competitive, it is not actively resisted by public or other organisations, and it is firmly placed in a fit-for-purpose legal and regulatory framework. However some of the challenges related to these themes either do not fall neatly in one of the categories discussed in the previous chapters, or bridge several categories. These issues are called here 'cross-cutting', and are briefly discussed in this section[15].

One of the central themes of any emissions reduction technology strategy is its scalability to achieve an optimal balance of significant climate mitigation, natural resource and capital management and overall societal benefit. This suggests the following question. Can and should CCS grow to cover a future fossil fuel economy larger than today's? Potential scalability is the basic incentive for large, early investments in the climate mitigation technology development, e.g. hydrogen, fuel cells, CCS, photovoltaics, increased energy efficiency, biomass-based fuels, etc.

The primary cross-cutting issue for implementing CCS is therefore judged to be the potential to scale up CCS to meet the needs of a carbon-constrained energy economy in which fossil fuels continue to dominate in the next generation or two of energy conversion plant lifetimes[16],. Many technological/geological/economic mixed factors influence the scalability of CCS:
1. CCS as a bridging option to sustainable energy - wishful thinking?
2. Capacity of high-storage-integrity geological reservoirs and their proximity to point sources of CO_2.
3. Overall effectiveness of CCS in reducing and avoiding CO_2 emissions.
4. The availability of competitively-priced and reliable fossil fuels in the global market.
5. Associated environmental externalities of fossil fuel production and consumption that are not solved by CCS or possibly any technology strategy.

Each of these issues is discussed briefly below.

6.1 CCS as a bridging option - wishful thinking?

It is generally recognised that there exists an implicit competition between development of CCS and development of other low-carbon technologies such as nuclear energy and renewable energy technologies. In other words, the practical scalability of CCS and other energy systems are in fact linked to some degree because society does not have resources for both a large scale-up of CCS and for replacing the current nuclear energy systems with new nuclear energy systems, or for a large scale-up of renewable energy systems. An initial choice of one could unavoidably delay and possibly limit the effectiveness of the others. Some evidence for this is seen in the results from integrated macroeconomic (top-down) models of energy development and emissions trends in the next 100 years (IPCC 2005), which show that the relative share of renewable energies remains low for the whole century, and the relative share of fossil fuels remains high due to the implementation of CCS. In other words, these models can be interpreted to predict that CCS will out-compete renewables, delaying their implementation. Thus CCS will not function as a bridge to fully renewable energy systems. This begs the question of what an optimal portfolio of a range of energy sources contains and how to achieve it, and although relevant for the question of scalability, it is beyond the scope of this analysis.

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15 It is part of the mandate of the ACCSEPT project to continuously identify new cross-cutting issues as they are made known, so this section must necessarily be viewed as a snap-shot of the current situation.

16 I.e. the next 50-80 years.

6.2 Storage capacity of high-integrity geological reservoirs and their proximity to point sources of CO_2

A very real and practical challenge for geological storage site evaluators is the fact that the most important mapping technique, i.e. seismic data collection and interpretation, may not be effective in many areas due to a number of reasons. Some of these challenges are described in a real case in Gupta *et al* (2004). Top-down estimates of geological storage capacity in the EU area have been performed using traditional regional mapping techniques, but lack the detail necessary in a bottoms-up process that would be applied in a process of evaluating long-term storage integrity for specific CCS project needs. This applies to candidate storage site costs as well, i.e. costs have until now only been documented on an aggregate top-down level, whereas actual site preparation, operation and final sealing costs estimated in a bottom-up analysis may be much higher. A similar situation exists for transport costs that until now have only estimated costs based on a 2 or 3 parameter characterisation of topography, i.e. have not taken full consideration of actual pipeline path costs and challenges related to Land Use Planning.

6.3 Overall effectiveness of CCS in reducing CO_2 emissions

Many of the claimed 'zero emission' technology solutions studied today fall significantly short of this vision. A prime example is the technology of amine scrubbing[17] of exhaust gases to produce a concentrated CO_2 stream, which will probably only capture 80-90% of the CO_2 emissions produced. Essentially all transport processes of CO_2 imply some energy consumption that will be provided by fossil fuels, e.g. use of ship transport of CO_2 as a cold, pressurized fluid[18]. The process of liquefying CO_2 for practical ship transport requires about 100 kWh/tCO_2, and it is unclear whether the additional CO_2 emissions implied in this incremental energy will also be covered by CCS, or if the emissions will be simply covered by accounting and not be captured. After liquefied CO_2 has reached the storage site, additional energy will be required to re-gassify the CO_2 because injecting cold CO_2 into a geological reservoir will cause substantial fracturing of the reservoir near the injection well, thereby potentially compromising the sealing capacity of the storage reservoir. Again, the question is whether this implies a new source of CO_2 emissions and if they will be captured or if the new emissions simply go into the CO_2 accounting as a net increase. Each new source of CO_2 emissions along the entire chain of CCS can in theory be captured, but in practice they may be too small and too dispersed, which means they will reduce the overall effectiveness of CCS as an emissions reduction technology strategy[19].

6.4 The availability of competitively-priced and reliable fossil fuels in the global market in the next 5-50 years

Prices of all fossil fuels are somewhat linked due to the options that many end users have to switch between them to some degree. As a consequence, a confluence of delicate imbalances between supply and demand and pricing of supply risk in both the global oil markets and regional natural gas markets appears to have drawn all fossil fuel prices upwards, including coal, which in very strong contrast is both ubiquitous and readily available at predictable and stabile production costs. Forecasting oil and natural gas availability and prices in the next 1-50 years is laden with vested interests and controversy. This project has no ambition to analyze this, but simply notes that many prominent energy analysts warn of impending limits to supply growth of conventional oil and natural gas thereafter followed by a slow and irreversible fall in primary production of these.

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17 This process can only capture 80-90% of CO_2 emissions because capturing the last 10-20% implies quantum increases in costs that are effectively prohibitive.

18 This may be relevant for point sources near shore whose total storage volumes are modest and whose most attractive storage sites are offshore at distances that prohibit cost-effective use of pipelines.

19 Maximum emissions in a scenario of stabilising atmospheric CO2 at 500 ppm are estimated to be 2 Gt CO2 in 2100 (IPCC 2001).

6.5 Associated environmental externalities of fossil fuel production and consumption that are not solved by CCS

The prime example of this is the situation for coal, which in many areas on all continents is strip-mined leaving vast scars in the landscape. Shallow tar sands and bitumen have similar problems, although these fossil resources lie outside the EU[20].

Deep coal mines have also a statistically significant risk of death, injury and debilitating disease for mineworkers, and a significant issue of coalbed methane emissions, which also contribute to climate change. Deep and shallow coal mines have a small but significant probability of spontaneously igniting such that they can potentially burn uncontrollably for years, releasing large quantities of a range of climate change and pollution agents.

Heavy oil and coal combustion processes also produce in most cases other associated pollutants (e.g. trace metals, NO_x) that CCS systems may not directly solve, and which will require additional efforts to mitigate. In other words, successful implementation of CCS on coal may reduce its climate change effects but may also result in large increases in trace metals and NO_x emissions with unacceptable environmental consequences[21].

[20] In other words, the entire supply chain of fossil fuels must be considered in terms of emissions, worker safety and other environmental effects, and that many of the supply chains begin outside of the EU.

[21] The Large Combustion Plant directive that has recently gone into effect will lower unit emissions of SOx, NOx and trace metals, but places no overall cap (a similar directive in the USA in fact places an overall cap and allows for emissions trading of SOx, NOx and soon mercury), meaning that unit emissions can fall but scale-up of coal industry can still result in an increase in absolute emissions.

7. Preliminary gap analysis

From a legal point of view, the main gaps appear to relate to domestic law. In particular, analysis is required of the extent to which current EU and national legislation regarding property rights and liability might apply to CCS activities. Preferably, existing regulatory arrangements will be utilised and, where necessary, amended to fill gaps and provide certainty. For example, laws regarding mining, oil and gas operations, pollution control, waste disposal, nuclear waste storage, pipelines, property and liability may be relevant and extendable to CCS. The state of knowledge concerning public international law's relevance to CCS is more extensive. It is well-recognised that clarification (and possibly amendment) is required of several provisions in the marine protection treaties, which have the potential to act as a barrier to CCS activities. Guidance is also required regarding aspects of CCS under the international climate change regime.

In the regulatory field, which is a field very much in progress, there are several issues that need to be resolved before CCS can be broadly deployed. The main current showstopper is that the permitting requirements for site-selection and long-term monitoring are unclear at this point. It would be preferable if an international institution with indisputable credibility would develop standards related to those issues, which could then be used for national legislation as well as for international instruments such as the EU Emissions Trading Scheme and the CDM.

Strictly in terms of economic aspects of CCS, there are no real showstoppers for the development of CCS. However, there are several aspects that, despite the role they play in policymaking, do not receive sufficient attention and may lead to misinformed decision-making. Firstly, major models appear to use low values for the costs of CCS, which would result in an overestimation of the role of CCS in the mitigation portfolio. Secondly, the relative increase of the electricity price following large-scale application of CCS (as well as other mitigation options) will differ around the globe. As a consequence, the public in regions with low electricity prices might be more reluctant to accept CCS than elsewhere. This aspect is not taken aboard in any policy decision at the moment. Thirdly, the details of corporate decision-making depend on the cost distribution between upfront investment costs operational costs, as well as on the nature of the sector. The heterogeneity in the break-up of costs and in the parties involved in any CCS project is often not acknowledged in the policymaking process.

Public acceptance of a technology is essential for any type of deployment. In several other technology fields, such as nuclear energy and genetically modified organisms, unexpected public opposition has halted progress. The public is not well informed about CCS, although that might be changing with enhanced media attention. The limited and in several cases incomparable research into public perception of CCS yields a more neutral than negative opinion on CCS, and also points at two contextual conditions for CCS acceptance: climate change should be recognised as a problem, and significant CO_2 reduction as the only solution. The evaluation of public perception of CCS is impeded by the lack of information about both CCS and alternative mitigation options. Information campaigns on climate change, greenhouse gas reductions, and the technology of CCS might be important. It is also likely that there are also implications of the results in the areas above; a smaller increase in electricity costs as a result of CCS, and a reliable government with a trustworthy regulatory framework for the technology contributes are likely to increase acceptance. The comparison with lack of acceptance in other energy technologies, notably nuclear, could lead to interesting insights and lessons, but this has not yet been done.
The position of NGOs can also change the perception of a technology. At this point, their position varies highly, although none are vehemently against CCS as such, but also none favour it over renewable energy or energy efficiency. The NGO position is normally inspired by more nuanced conditional aspects: according to some, CCS should for instance not divert resources

from renewable energy and energy efficiency, and it should therefore not be sponsored by R&D money or by specific policy measures.

Lastly, several crosscutting issues were identified: the overall potential of geological storage and the difficulties in determining reservoir suitability, the upstream greenhouse gas emissions of CCS and externalities associated with continued use of fossil fuels, and the availability of affordable fossil fuels over the coming 50 years.

8. Major workshop discussions

On April 25 and 26, 2006, a workshop was held to discuss the issues identified in this report. The participants, twelve in total complemented by the project team, represented a broad range of stakeholders, including government, oil industry, electricity industry, academia, and environmental NGOs. The discussions were grouped into three main topics: CCS in the energy system (mitigation portfolio and decentralisation), public perception, and regulation. Rather than reaching consensus on the issues, the participants flagged major questions and controversies, agreed on a common language, and discussed the context. A summary of the points discussed is given in this section.

Mitigation portfolio and decentralisation:

- CCS is only one of the options in the mitigation portfolio and should be seen in the context of the other options - notably energy efficiency and renewable energy, but also nuclear energy.
- CCS can reduce the cost of mitigating greenhouse gas emissions. This may contribute to choosing more stringent stabilisation targets.
- Given a predetermined stabilisation target, large-scale introduction of CCS would replace the implementation of other mitigation options. Whether that is bad depends on the starting point. If the goal is to prevent climate change and therefore reduce emissions, CCS should qualify fully for all climate change-related government provisions (R&D funding, subsidies, CDM). For other goals, such as a fully renewable energy system, CCS should not be evaluated against the same criteria as other mitigation options.
- A risk-based approach could be used in evaluating the hierarchy of the portfolio options. Risks could be estimated for climate change, for safety and terrorism, for environment, and for security of energy supply. Some participants wanted to exclude nuclear energy upfront as an alternative mitigation option, noting that carbon constraints would also make it more attractive. Many felt that CCS could undermine the rationale for supporting nuclear.
- Given current technology[22], CCS implies centralisation. Whether it is an obstacle to decentralisation is unclear. On the one hand, CCS would divert political, institutional and financial resources from more decentralised approaches. On the other hand, the demand for electricity is growing so fast that new capacity is needed from both centralised and decentralised sources. Whether the potential deterring of CCS for decentralisation is a problem depends on national circumstances, optimism on renewables, and the ability of governments to set up policies to promote decentralisation.
- One cannot speak of CCS as one thing: EOR, CCS from coal versus gas, offshore or onshore: different options will have a different effect on acceptance.
- The availability of CCS in the mitigation portfolio may have two quite different effects: on the one hand, the urgency for climate change mitigation may be reduced because we have a 'fallback' option now; on the other hand the momentum may increase because mitigation now seems more achievable, particularly in countries with large coal reserves such as the US, China, India and South Africa.
- Structural implementation of CCS makes fossil fuel-based power more expensive and may thus act as an incentive to use other sources; but it depends on the requirements for CCS.
- It isn't clear whether the notion of CCS being phased in and eventually back out again in favour of renewables as a result of a targeted anti-CCS government measure is a realistic one, both due to technological lock-in, and the possibility that CCS deployment will displace learning and cost reductions in renewables.

Public perception:

[22] I.e. assuming that capture from small immobile sources is (energetically and economically) unfavourable.

- A distinction should be made between the perception of CCS in general and the public response to a single project.
- Many environmental NGOs and firms are still in the process of choosing positions. As it trusts environmental NGOs more, the lay public may base their position on CCS, at least in part, on the position of NGOs.
- The lay public currently has a low recognition for the climate and the energy problems. The level of knowledge about CCS, and other mitigation options, is generally low. The electricity sector and the climate problem are very complex. It is questionable whether the complicated message of the limited choice of energy options can be brought across to the general public.
- Public perception may also be influenced by the type of CCS project, the location (e.g. on or off shore) and whether new infrastructure needs to be put in place exclusively for the project. The perception that the highly profitable fossil fuel industry is receiving public money to solve a problem they caused themselves might lead to resistance.
- The public has seen many promises of new energy options that have not been able to live up to initial expectations. Examples include nuclear energy in the 1960s, and renewable energy in the 1970s and 1980s.
- Trust in the ability of governments to make the CCS option work better than former promises is key. The government should make a credible link between climate change and CCS, and should be transparent in the extent to which taxpayer's money is spent on a fossil fuel-based mitigation option.
- Public opposition to CCS, or a decision that CCS is not needed in Europe, could have negative spillovers by discouraging the growth of CCS in places where it might be more important such as developing countries.
- If the first few projects are successful, it will be hard to see how stakeholder opposition would manifest itself. This also argues for 'gold-plating' the first projects. A single failure may lead to a sharp rise in public opposition.
- CCS developers run risks in trying to earn public trust. How CCS is presented in the public is important. In discussing risks, they might draw attention to what are essentially industrial projects that no one would really concern themselves with if not pointed out to them. By the same token, if the public is unaware, and something does go wrong, the backlash will be all the more severe.
- In most places the state will need to be engaged in the development and/or facilitation of CCS: although a source of delay, CCS may benefit from state involvement in an open and transparent process with a lot of dialogue.
- The opposition to CCS would be related to the perception of how we could address climate change. If the public can be convinced that there are sufficient options in efficiency, renewables, and decentralisation, CCS opposition could rise. Greater acceptance of the urgency and severity of the climate problem will make CCS more acceptable.
- CCS could be seen as a 'first aid' solution, whereas renewables are the sustainable solution. If the public does accept the need for emergency responses to disasters, it might accept CCS if framed in those terms.

Policy and legislation:

- A strong, long-term and credible ('long, loud and legal') policy incentive is needed if CO_2 capture and storage is to be deployed.
- The EU Emissions Trading Scheme would be suitable, although the uncertainty about post-2012 incentives remains, even if the near-term price is too low to support the first commercial projects. Provisions for interim support for CCS to bridge the uncertainty gap in the ETS might be necessary if immediate deployment of CCS is deemed desirable.
- Alternative policies include capital grants, financial incentives beyond the ETS, capture-ready obligation for new power plants, decarbonised electricity certificates, etc. There will be tradeoffs between different mechanisms in terms of timing, feasibility and acceptability. There are still questions remaining about the most effective means of getting different tech-

nologies into the portfolio - e.g. efficiency maybe best through standards, not the market, while for others a clear carbon price is sufficient.

- Politicians try to avoid backing the wrong horse and prefer to develop a portfolio to hedge their risks so it makes sense to develop CCS in parallel with renewables.
- The UNFCCC could play a role in several aspects: it could a) provide a network function for information and experience exchange for CCS technology; b) coordinate the development of independent site and project criteria (also as input for the eligibility of CCS projects under the CDM) or c) develop 'best available technology' standards.
- The argument is often made now that we need CCS for China and India's coal development: is this genuine? While a strong argument in carbon terms, it may prove politically difficult to spend billions on clean power projects in rapidly growing industrial powers.
- A policy that makes support for CCS contingent on increasing funding for renewable energy and efficiency might assuage any concerns over diversion of funding.
- The stringency of site selection and associated certification requirements, are the most important determinants of how strict subsequent monitoring is needed.
- While there is likely to be emphasis placed on leakage rates, the concept is not generally perceived correctly: leakage will likely be caused by poor site certification and large leaks from a few sites, rather than small and gradual leakage from a lot of sites.
- Low-level and short-term leakage from storage is straightforward to account for: it has the value of the price of carbon and can be repaid at that rate when the leakage occurs. It is really the local health, safety and environment risks of potential larger leaks or accidents that will drive regulatory development. Also, the question how to account for long-term leakage, potentially beyond a climate regime, remains unanswered in current regulation.
- Legislation should focus primarily on storage, as capture and transportation are more conventional business practices, and legislation is largely already in place.
- Questions regarding storage and leakage include how long the reservoir should be monitored, who is responsible and liable in the longer term, what are the risks and how leakage should be defined.

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