Is CO_2 capture and storage ready to roll?

Reflections on social, economic, and regulatory requirements

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Within the context of rising overall awareness of the climate change problem, CO_2 capture and storage has risen rapidly on the policy agenda. Some Stakeholders have suggested that technology, cost and legal questions around CCS are all but solved. However, while policymakers embark on the agreement of national, European and international legislation on CCS, a number of challenges arise. This paper reviews the progress of CCS towards a legally embedded mitigation option, and identifies three major conditions for the acceptability of CCS deployment: social acceptance by stakeholders and the lay public, robustness of economic and cost data, and legal and regulatory consistency. Technical maturity and reliability are important crosscutting issues that need to be fully addressed before any of the other areas can be solved. It is concluded that, although legal and regulatory issues are close to being resolved, the role that CCS may play in the global energy system has likely been overestimated in system models, which is partly due to transparency and information problems. In addition, resistance from environmental organisations may have to be reckoned with and social acceptance of CCS remains one of its most prominent unknowns.

I. Introduction

CO_2 capture and storage (CCS) is increasingly seen as a potentially attractive means of mitigating climate change. The technology is different from mitigation options such as renewable energy or nuclear energy as CO_2 is still produced but the technology prevents a large proportion of its emission to the atmosphere and therewith its contribution to climate change. As a relatively new technology, CCS is not yet fully embedded in regulatory and legal frameworks. Although some experts suggest that technology, cost and legal questions around CCS are all but solved, a number of challenges have arisen in national and European as well as international contexts. This paper reviews the progress of CCS towards a legally embedded mitigation option[1]. It identifies and assesses three major conditions for acceptable CCS deployment: social acceptance by key stakeholders and the lay public, robust assessments of economics and costs and legal and regulatory consistency. Although these conditions are not entirely mutually exclusive, their separate assessment generates useful insights for law and policymaking.

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1 This paper leans heavily on the results of the European Commission DG Research ACCSEPT project. More information on the project, as well as underlying publications is available via www.accsept.org.

The IPCC identifies CCS as "a process consisting of the separation of CO_2 from industrial and energy-related sources, transport to a storage location, and long-term isolation from the atmosphere"[2]. CO_2 capture can be applied to large CO_2 point sources, such as electricity plants or steel factories. The storage of CO_2 can be done in saline formations, coal beds, or in oil or gas fields. The latter include depleted oil and gas fields, but also fields that are still in production. In those cases, the CO_2 may sometimes be used to extract a higher proportion of oil or gas in a field, resulting in higher fossil fuel recovery. This is called Enhanced Oil or Gas Recovery (EOR or EGR), or Enhanced Coalbed Methane Recovery (ECBM) for coal beds, and can actually make the costly CCS-options more economically feasible.

For a long time, CO_2 capture and geological storage was viewed as an unlikely near-term option to address climate change. The Intergovernmental Panel on Climate Change, for instance, qualified it as unlikely in its Second Assessment Report,[3] and more feasible in its Third Assessment Report.[4] The IEA Greenhouse Gas R&D Programme organised its first conference on CCS in 1992, involving about a hundred participants and limited to mostly technical research, whereas its latest conferences attracted over a thousand participants including from disciplines such as economics, policy studies, and sociology. Evidence that the technology was finally viewed as a major mitigation option can be found in publication of a major IEA report[5] and the IPCC Special Report on CCS. It was subsequently discussed in the UNFCCC context, among other issues as an option for the Clean Development Mechanism (CDM).[6] Although by no means uncontroversial to some stakeholders, currently CCS features prominently in climate mitigation strategies of all industrialised countries as well as in many large, coal-dependent emerging economies. The European Commission,[7] explicitly mentioned CCS as a necessary technology to achieve deep CO_2 emission reductions.

This paper will review the state of affairs in the three areas that have been identified as most relevant: social, legal and economic. Section II introduces those areas; why they are important and how they can be framed. Section III reviews the progress in the different fields based on literature and recent and ongoing policy developments. Section IV then discusses the remaining gaps in those areas, what can be done to address them, and what the risks are if they remain unaddressed.

II. Framing issues

The lack of certainty concerning whether the general public would approve of CCS is regarded as one of the major barriers to CCS deployment. Indeed, some in industry have referred to public acceptability as a "potential show stopper".[8] In part, this is because studies all find quite low levels of awareness of CCS, which makes the situation inherently less stable than for other better-known low-carbon technologies such as nuclear power, wind turbines or solar panels. Related to the issue of lay public perception is the issue of stakeholder perception. Local and national environmental groups constitute an important shaping influence upon public opinion, particularly at a stage where the public itself lacks information. Studies of credibility have found that these groups are most trusted by the general public.[9]

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

3 IPCC (1996): Climate Change 1995: Economic and social dimensions of climate change. Contribution of Working Group III to the Second Assessment of the Intergovernmental Panel on Climate Change. J.P.Bruce, H.Lee, E.F.Haites (Eds), Cambridge University Press, UK. pp 448.

4 IPCC (2001): Climate Change 2001: Mitigation. Contribution of Working Group III to the Third Assessment Report of the Intergovernmental Panel on Climate Change [Metz, B., O. Davidson, R. Swart, and J. Pan (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

5 IEA (2004). Prospects for CO_2 capture and storage. Technology paper: IEA/OECD, Paris, France; IEA (2006): Energy technology perspectives: Scenarios and strategies to 2050. IEA/OECD, Paris, France.

6 UNFCCC (2005). Decision -/CMP.1: Further guidance related to the Clean Development Mechanism; available on http://unfccc.int/files/meetings/cop_11/application/pdf/cmp1_24_4_further_guidance_to_the_cdm_eb_cmp_4.pdf; consulted on August 13th, 2007.

7 EC (2007). Communication from the Commission to the Council and the European Parliament: Sustainable power generation from fossil fuels: aiming for near-zero emissions from coal after 2020; COM (2006) 843 final.

8 Hill in House of Commons (HoC) (2006): Meeting UK energy and climate needs: the role of carbon capture and storage. Science and Technology Committee, Report HC 578-I, London: The Stationery Office Limited. Hill's testimony.

9 Eurobarometer (2006): Attitudes towards Energy, Special Eurobarometer 247.

Legal and regulatory consistency is an essential condition for lawmaking; national, EU and international legislation needs to be compatible. It is therefore paramount to make sure that CCS operations are consistent with existing law and do not counteract other policies. This can be done through modification or extension of existing law, or through the design of new legislation that is fit-for-purpose for CCS and would partly overrule earlier agreement. There is a wide range of legal and regulatory issues that need to be resolved in order to carry out CCS activities.

For instance, the level of technological maturity is one of the determinants for the most appropriate policy instrumentation to advance the technology.[10] If there is much experience with a technology and insights on appropriate monitoring and inspection are advanced, overregulation would be unnecessary and unlikely. In the case, however, that uncertainties remain, some degree of overregulation can be justified in order to set the highest standard, consistent with the precautionary principle. The applicability of EU Directives, international law, incentives for CCS and liability issues are therefore paramount.

Costs and economics of CCS determine to a large extent the decision taken, by both policymakers and by firms, on CCS projects. Numerous studies on CCS and estimates of costs exist in the peer-reviewed literature, and economic modelling has been carried out with various models, the present state of affairs is comprehensively assessed in the IPCC Special Report on CCS,[11] and in a number of IEA studies.[12] However, the wealth of publications hides the fact that many information gaps and uncertainties still exist. These should be clarified to a satisfactory level before any government embarks upon a policy of structurally enabling or supporting CCS.

III. Conditions for CCS: status and progress

1. Social acceptance

Social acceptance of a technology depends on the level of familiarity and comfort of individuals and communities with a technology. If the technology has never been tested, this level of comfort and the support for the technology are likely to be low. It is therefore important for the public acceptability of CCS that there is experience through large-scale, real CCS projects and that research results are disseminated widely.

The lay public perception of CCS has been the subject of some research. Although the studies are not done in an directly comparable way, some general conclusions can be drawn. There are a few empirical studies of public perceptions of CCS, with six separate studies having been reported in the EU region (two in the UK, two in the Netherlands, one in France and one in Sweden). Further studies of public perceptions have been done in the USA, Canada, Japan and Australia. Table 1 summarises the work to date. Reiner et al[13] offer a comparison of four countries using the same questionnaire including two EU (UK and Sweden) and two other countries (US and Japan). One of the few actual experiences of public perceptions is the Ocean Field Experiment in Hawaii, a case-study which has illustrated how bureaucratic obstacles, a few dedicated activists and slow recognition of the need for public outreach derailed the project.[14]

(see Table 1, opposite page)

Aside from the more quantitative, representative studies there have been very few qualitative studies such as focus group work or interviews with laypeople.[15] Acceptance of CCS, where it occurs, appears frequently to be "reluctant" rather than

10 Sandén, B.A. and C. Azar (2005): Near-term technology policies for long-term climate targets – economy wide versus technology specific approaches. Energy Policy 33:1557-1576.

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

12 IEA (2004). Prospects for CO_2 capture and storage. Technology paper: IEA/OECD, Paris, France; IEA (2006): Energy technology perspectives: Scenarios and strategies to 2050. IEA/OECD, Paris, France.

13 Reiner, D.M., .E. Curry, M.A. de Figueiredo, H.J. Herzog, S.D. Ansolabehere, K. Itaoka, F. Johnsson, M. Odenberger "American Exceptionalism? Similarities and differences in national attitudes towards energy policy and global warming" Environmental Science and Technology 40 (March-April 2006): 2093-2098.

14 De Figueiredo, M.A. (2002): The Hawaii Carbon Dioxide Ocean Sequestration Field Experiment: A Case Study in Public Perceptions and Institutional Effectiveness, Masters Thesis, Massachusetts Institute of Technology.

15 Shackley, S., C. McLachlan and C. Gough (2005): The public perception of carbon dioxide capture and storage in the UK: Results from focus groups and a survey, Climate Policy Vol.4(4), pp 377-398; Huijts, N. (2003): Public Perception of Carbon Dioxide Storage, Masters Thesis, Eindhoven University of Technology.

Table 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 stake-holder interviews	CSIRO/ University of Queensland (6/2005)
Australia	1080 respondents based on a representative sample of the Australian public	CSIRO/ University of Queensland (2/2007)
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)
France	1000 face-to-face interviews conducted by TNS-Sofres	CIRED (4/2007)
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 some 1,200 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)

"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. Public awareness raising activities have been limited and are largely uncoordinated between various national and international governments, CCS-interested companies such as Vattenfall or BP, and environmental NGOs. There has been incidental consultation across projects, but no sustained effort to coordinate these many different activities. Recently, in various European countries, the attention devoted to CCS in various media has increased[16] but the impacts of such developments on public awareness are difficult yet to measure or establish.

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) there must be acceptance of the need for large reductions in CO_2 emissions to reduce the threat of global climate change.[17] Once these conditions are met, CCS may come to be regarded as one of the range of major mitigation options.

16 IEA Greenhouse Gas R&D Programme (2006). IEA Greenhouse Gas R&D Programme (2006): IPCC SRCCS: Review of media impact. Report number 2006/TR2, Cheltenham, UK.

17 IPCC (2005).

Acceptance of the two conditions, however, does not imply support for CCS. It 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 as an option with potential long-term risks.

Research has also established that, in arriving at opinions such as those concerning CCS, the lay public often relies on the viewpoint of organisations by which they feel represented or towards which they feel some affinity. In that vein, it is important to assess the attitude of environmental non-governmental stakeholders, which are more often relied upon for providing a perspective than governments or industry.[18]

There have been very few independent studies of the involvement in, and perceptions, of stakeholders regarding CCS, and some of them may refer to opinions that have evolved since. Lee et al.[19], for instance, rely on initial focus groups conducted in 2001 when they 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". 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".[20] On the other hand, Lee also argued that some NGOs were "developing a more positive opinion on carbon capture and storage, realising that a transition phase is likely to be needed before renewable energy can become more cost-effective and widely implemented."

Anderson[21] 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". NGOs may perceive that CCS is already being sufficiently promoted by industry and government to require or justify extensive additional support. For this reason, they often object to the spending of public money on CCS. NGO opposition against allowing for CCS in the CDM is more widespread than opposition against CCS in the EU ETS on the argument that developing countries might be used as guinea pigs for a relatively new technology.[22] Anderson confirms that additional reasons why NGOs are frequently unenthusiastic or hostile about CCS include the potential effects upon other mitigation options, potential adverse environmental impacts arising from leakage and continuation of coal mining. A collective of NGOs in California recently played a major role in blocking the creation of fit-for-purpose CCS regulation, citing reasons of "environmental injustice".[23]

During the second half of 2006, a new stakeholder survey was held among 512 stakeholders from across Europe.[24] The study surveyed opinion regarding the role of CCS in Europe's possible energy futures. The large majority of respondents were from the energy industry, research and government sectors, with smaller numbers from environmental NGOs and from national parliaments. 40% of the sample believed that CCS was "definitely necessary" in their own country, 35% that it was "probably necessary", 12% that it was "only necessary if other options fail to live up to current expectations", 8% that it was "probably not necessary" and 4% that it was "definitely unnecessary". Their belief in the need for CCS tended to increase when moving from the national to the EU to the global scale. The respondents tended to regard the risks of CCS as being moderate or negligible and did not perceive very negative impacts arising from investment in CCS upon efforts at improving energy efficiency and reducing energy demand. There were large differences, however, between the responses of NGOs (5% of sample) and parliamentarians (4% of sample) and those of energy industry, governmental and research

18 Huijts, N. (2003): Public Perception of Carbon Dioxide Storage, Masters Thesis, Eindhoven University of Technology.

19 Lee, A., D. Christensen, F. Cappelen, J. Hartog, A. Thompson, G. Johns, B. Senior, M. Akhurst (2004): Policies and Incentives Developments in CO_2 Capture and Storage Technology: A Focused Survey by the CO_2 Capture Project, CCP Policies and Incentives Team.

20 CAN-Europe (2006): EU public consultation on future commitments post 2012 on climate change.

21 Anderson, J. (2005): A Critical Review of CO_2 Capture and Storage: NGO and Public Acceptance Issues. Institute for European Environmental Policy, IEEP, London.

22 Goerne, G., von (2007): The impact of CCS and the CDM on the future climate regime. Presentation at the SBSTA side event by the Wuppertal Institute, May 15, 2007. Bonn, Germany.

23 Williams, J., R. Suwol, A. Johnson Mazaros, et al., (2007): Letter to Assembly Member Loni Hancock and Members of the Assembly Natural Resources Committee. April 20, 2007.

24 Shackley, S., H. Waterman, P. Godfroij et al., (2007): Stakeholder perceptions of CO_2 capture and storage in Europe: Results of the EU-funded ACCSEPT survey. Available on www.accsept.org, consulted August 13th, 2007.

& academic stakeholders (28%, 13% and 34% of the sample respectively). NGO respondents tended to be the most skeptical concerning the role of CCS and to have a more negative perception of the potential risks and negative impacts on other mitigation options than other stakeholders.

In summary, the position of NGOs on CCS remains rather contingent and hard to characterise with any degree of certainty. For example, some NGO's 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, principles tend to be broad, but specific positions are often quite reactive. One could imagine that the lay public refuses to rely on NGOs when their positions are difficult to understand, but also that their indecisiveness leads to less trust in the option and thus decreasing support. It is uncertain what social acceptability of CCS such dynamics would eventually yield.

2. Legal and regulatory consistency

The legal and regulatory field around CCS is particularly dynamic, especially in the European Union. In its strategy papers, the European Commission has announced a list of proposals that would arrange for the applicability of EU Directives to CCS, address liability issues, and provide incentives for CCS through the ETS and potentially other mechanisms.

a. Applicability of 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.[25] These requirements will typically involve environmental impact assessments and/or permitting as well as requirements related to areas that CCS might impact on. The main directives which are relevant to 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 environmental liability (2004/35/EC). These directives were created without consideration of CCS. In addition to the EU Directives, there is Member State regulation which should be consistent with EU legislation.

Recently, the European Commission released a study that looked into the options for how to regulate CCS in the EU Directives landscape, and what would be a way of both ensuring safe capture, transport and storage of CO_2 by covering all the gaps existing legislation may leave, and allowing for smooth implementation of modifications in existing Directives by making the changes relatively undisruptive. An example is the question of defining CO_2 for storage as a waste. If CO_2 were defined as a waste, practical legislation in the Landfill Directive would apply, which would make a new Directive arranging issues like financial liabilities superfluous (see Table 2). However, as CO_2 is injected as a liquid and storing liquid waste is prohibited under the Landfill Directive, less administrative difficulties might arise should a new Directive on CCS be introduced. *(see Table 2, page 408)*

Table 2 shows in some detail what components of the CCS chain might be covered by the various existing European Directives. Storage stands out as the most complex component, having a patchwork of requirements on various timescales and spatial dimensions. It appears that the EU Emissions Trading Scheme (ETS) Directive will provide for inclusion of CCS as an opt-in anyhow, which would already lead to coverage of a large amount of the potential impact issues associated with CO_2 storage, but the coverage is not complete. The : Integrated Pollution Prevention and Control (IPPC) and Landfill Directives seem likely candidates to cover the remaining gaps, but the latter has serious inconsistencies related to classification of CO_2 as a waste. If IPPC would be applied, the Environmental Liability Directive would cover long-term liability issues and additional legislation, mirroring the Landfill Directive, could cover remaining issues. It is the Commission's view that CCS would then be pragmatically and responsibly governed through a combination of existing and new legislation.[26]

25 IEA Greenhouse Gas R&D Programme (2003). Review of international conventions having implications for the storage of carbon Dioxide in the Ocean and Beneath the Seabed, Report PH4/16: Cheltenham, UK.

26 Brockett, S. (2007). Regulatory and legal issues: development of an enabling legal framework for carbon capture & storage in the EU. Presentation made on a Stakeholder Consultation meeting, May 8th, 2007, Brussels, Belgium.

Table 2: Directives and their bearing on elements of CO_2 capture, transport and storage[27]. Question marks indicate that the applicability of the Directive is either unknown or depends on specific developments or decisions.

Directive	Capture	Transport	Storage
EU ETS	· Recognition of CO_2 not emitted	· Leakage risks for climate change	· Site selection, characterisation and risk assessment? · Risk management? · Monitoring underground and CO_2 purity · Remediation obligations · Conditions for site closure? · Post closure site stewardship · Ongoing liability
Environmental Impact Assessment	Not applicable	· Appropriate routing	· Site selection? · Risk management? · Aboveground operations?
Integrated Pollution Prevention and Control (IPPC)	· Use of BAT; NOx, SO_x, solid waste emissions	Not applicable	· Site selection, characterisation and risk assessment? · Risk management? · Aboveground operations · Monitoring underground and CO_2 purity · Remediation obligations? · Conditions for site closure · Requirements decommissioning? · Post closure site stewardship · Ongoing liability
Seveso II	· Local risks for environment, health and safety?	· Local risks for environment, health and safety?	· Site characterisation and risk assessment? · Risk management? · Monitoring underground · Remediation obligations? · Requirements decommissioning?
Environmental Liability Directive Not applicable	· Local risks for environment, health and safety?	· Remediation obligations	· Post closure site stewardship · Ongoing liability?
Landfill Directive	Not applicable	Not applicable	· Site selection, characterisation and risk assessment? · Risk management, including financial securities? · Aboveground operations · Monitoring underground and CO_2 purity · Remediation obligations
Member State legislation	· Local risks for environment, health and safety	· Local risks for environment, health and safety	

b. Liability issues

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.[28] Literature specifically addressing liability regimes for CCS is sparse. de Figueiredo et al[29] note that liability for geological storage derives from three major sources:

– Operational liability: the liability associated with capture, transport and injection of CO_2.

27 Zakkour, P. and A. Evers (2007). Task 2 Discussion Paper: Choices for regulating CO2 capture and storage in the European Union. Report for DG Environment by ECN, ERM, Norton Rose and the Central Mining Institute. http://www.ecn.nl/fileadmin/ecn/units/bs/Transitietechnologieen/ Task_2_Choices_for_regulating_CO2_capture_and_storage_in_the_EU.pdf; consulted on July 23rd, 2007.

28 Flory, A., and J. Podkanski (2005): Legal aspects of storing CO_2. International Energy Law & Taxation Review: Thomson, Sweet and Maxwell, Andover, UK.

29 De Figueiredo, M.A., D.M. Reiner, and H. Herzog (2003): "Towards a long-term liability framework for geological carbon sequestration", Technology, Management and Policy Program and Laboratory for Energy and the Environment, MIT.

- Climate liability: the liability under 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 or the environment.

Operational liability issues for underground storage are similar to current, well-managed issues in the oil and gas industries and are therefore not expected to raise any particular problems. There is ample experience with transporting corrosive gases like CO_2 in pipelines on large scales, and although,some impacts will arise, it is likely that risks can be managed.

Climate liability will largely be dealt with under the accounting rules of any applicable climate change regime.[30] The fact that there is a possibility of non-permanence makes it necessary to incorporate liability for future releases into accounting schemes.[31] Perhaps even more complex will be the inclusion of CCS in emissions trading schemes, such as the EU ETS. Zakkour[32] 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 Member States' licensing and permitting regimes because storage involves longer timescales and different regimes to those in the EU ETS.

The legal issues considered in 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, but the issue lies in whether the entity with long-term liability should be public or private.[33] Another potential issue is the need for joint liability where several operators are injecting into the same formation.[34]

c. Incentives for CCS

We already discussed the pending inclusion of CCS in the EU ETS earlier in this paper, as well as the consequences for the legislative landscape in the EU. How CCS would be included, particularly whether a CCS project should be opted in as one activity involving CO_2 capture, transport and storage, or whether the components should be separate installations with their own allocations, remains an issue, but it will be likely that this is resolved by the end of 2007.[35] Given current expectations of fuel and carbon prices, as well as regulatory uncertainty, it is questionable, however, whether the ETS would give a sufficient incentive for CCS projects.[36] Complementary policies are therefore considered, both at the Member State and the EU level. One of the considerations is the maturity of CCS. As CCS consists of different components in different development stages, a policy package might also feature a range of incentives to make it appropriate for oxyfuel combustion, which is in the demonstration phase, as well as Enhanced Oil Recovery, which is a much more mature technology.

Member State policies would most likely involve subsidy or tax relief schemes such as investment subsidies, feed-in tariffs, or a guaranteed CO_2 price. These instruments are unlikely to show much reduction of efficiency of the ETS because of the scope of the Member State market distortion is likely low on the European scale. Environmental organisations, however, may oppose such schemes as they are more likely to displace resources for other mitigation options. In addition, those policies tend to pose an important part of the financial risk of

30 IEA Greenhouse Gas R&D Programme (2004). Overview of long-term framework for CO_2 capture and storage, Report PH4/35: Cheltenham, UK.

31 Bode, S, and M. Jung (2005): Carbon dioxide capture and storage (CCS) – liability for non-performance under the UNFCCC (HWWA Discussion Paper 325), Hamburg Institute of International Economics.

32 Zakkour, P., C. Girardin, L. Solsbery, S. Haefeli, and P. Murphy (2005): Developing monitoring, reporting and verification guidelines for CO_2 capture and storage under the EU ETS. UK Department of Trade and Industry, 2005.

33 IEA Greenhouse Gas R&D Programme (2004).

34 Wall, C, C. Bernstone, and M. Olvstan (2004): International and European legal aspects on underground geological storage of CO_2. SwedPower/Vattenfall, 2004.

35 Brockett, S. (2007). Regulatory and legal issues: development of an enabling legal framework for carbon capture & storage in the EU. Presentation made on a Stakeholder Consultation meeting, May 8th, 2007, Brussels, Belgium.

36 Coninck, H.C., de, and H. Groenenberg (2007). Task 3 report: Incentivising CO_2 capture and storage in the European Union. Report for DG Environment by ECN, ERM, Norton Rose and the Central Mining Institute. http://www.ecn.nl/fileadmin/ecn/units/bs/Transitietechnologieen/Task_3_Incentivising_CO2_capture_and_storage_in_the_European_Union.pdf; consulted on July 23rd, 2007.

CCS projects with national governments, which have the lowest insight in the actual costs and risks of CCS.[37] EU-wide structural policies, particularly a mandate, would have advantages in terms of consistency and environmental organisation support, but the political feasibility of such more drastic measures is low as some Member States may find a mandate a disproportionally strong measure.

As a European incentive mechanism for CCS nears completion, through the ETS and possibly supplemented by additional policies, policy development in other Annex-I countries varies. In the United States, policy is mostly state-based, and is determined by how urgent the climate change problem is perceived (e.g. California), or whether the state sees a possible economic advantage in developing CCS for coal-to-liquids (e.g. coal-reliant states such as Wyoming). In Australia, the federal government provides investment subsidies for individual projects. Although such incentives are not structural, the willingness of the governments does attract investors particularly for demonstration projects, as various project announcements in Australia and the United States make clear. The EU might also consider some form of investment support scheme for the 10-12 full-scale demonstrations it intends to realise by 2015.[38]

In non-Annex-I countries, currently the only incentive for CCS would be through the Kyoto Protocol's CDM. Inclusion of CCS in the CDM faces technical and procedural challenges similar though not identical to those in the EU ETS. However, the debate at international negotiations quickly turned highly controversial, with a number of non-Annex I Parties and environmental organisations vehemently opposed[39] and most Annex-I countries and industry organisations enthusiastically supportive.[40] The deadlock during the negotiations at COP/MOP2 in Nairobi led to a procedural compromise for observer and Party submissions, further discussion during COP/MOP3, and a decision on the issue at COP/MOP4 (in 2008). The positions are currently so far apart that a common ground on this issue alone is hard to imagine, which means that resolution may ultimately need to be tied to a package of issues.

d. International law

From an international law perspective, there may be legal barriers to the effective development of CCS in light of existing international regimes. Many of the international agreements use defined terms to delineate the scope of their coverage. The terms will determine whether a particular activity related to CCS is covered by a particular regime, and if so, how it is regulated. Where it is not clear whether a CCS activity falls within or outside the scope of a defined term in a particular legal regime, this may need to be clarified to provide regulatory certainty. 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.

It was recognised in an early stage that marine treaties, particularly the Oslo-Paris Convention (OSPAR) and the London Convention and its Protocol, posed unintended barriers to CCS. Several countries interested in CCS, or even practicing it already (Norway) therefore started negotiations on addressing the barriers. Agreement on amendments of the London Protocol was reached in February 2007, including guidelines on how to perform CCS operations in a manner that would not harm the marine environment, and OSPAR followed in June 2007. With that, major barriers in the marine international law seem to have been addressed.

Apart from marine protection treaties, 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

37 Ibid.

38 EC (2007).

39 Miguez, Jose (2007). Brazil and CCS/CDM. A Brazilian Perspective on CCS. Presentation at the SBSTA side event by the Wuppertal Institute, May 15, 2007. Bonn, Germany; Goerne, G., von (2007): The impact of CCS and the CDM on the future climate regime. Presentation at the SBSTA side event by the Wuppertal Institute, May 15, 2007. Bonn, Germany.

40 Watanabe, R., R. Duckat, and W. Sterk, 2007. Carbon dioxide capture and storage under the Clean Development Mechanism. JIKO Policy Paper 4/2007, Wuppertal Institute for Climate, Development and Energy, Germany. UNFCCC (2006). Submissions on CO_2 capture and storage and the Clean Development Mechanism. Available via http://unfccc.int/meetings/sb24/in-session/items/3716.php; consulted on July 23rd, 2007.

Table 3: 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[41]

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

Notes: Costs of Enhanced Oil Recovery instead of normal geological storage can be obtained by subtracting 20 to 30 US$/t$CO_2$.
The costs are in US$ 2002.
Oil prices from 2003 are used, amounting to about 20 US$ per barrel. Current oil prices are about a factor 3 higher.

Transboundary Movements of Hazardous Wastes, and the Convention on Biological Diversity. They pose less of a challenge to CCS development and are not generally considered in the literature.[42]

3. Predictability of economics and costs

Numerous studies on CCS and costs exist in the peer-reviewed literature, and economic modelling has been carried out with various models. The present state of affairs is comprehensively assessed in the IPCC Special Report on CCS,[43] and in a number of IEA studies.[44] The IPCC Special Report on Carbon dioxide Capture and Storage, for instance, 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. *(see Table 3)*

These numbers look robust and trustworthy, as they are based on bottom-up engineering costs, and the wide ranges seems to take into account uncertainties. However, the wealth of information hides the fact that many gaps and uncertainties still exist. Filling these gaps and dealing with these uncertainties is problematic because of a number of information deficiencies. They include:[45]

– Referencing same work: despite the rich number of engineering-cost studies, most of those studies use data from a very limited amount of base studies. The body of literature creates the impression that many sources confirm the same thing, but in reality, those many sources originate from a few studies
– Confidentiality: CCS is an option that evolved largely from existing, commercial technologies. These have not been developed by academic researchers, who tend to publish early results in journals, but are developed by corporate entities that are bound by commercial interests and hence confidentiality. Many of the specifics of technologies and cost data are therefore not fully available, and the validity of many assumptions is difficult to assess without access to real project data.
– Technology advocacy and optimism: There is currently a group of around a thousand to two thousand experts worldwide that work on CCS, up from a couple of hundreds only two or three years ago. Many of them became convinced of the virtues of CCS and are engaged in promoting the option, to a greater or lesser extent, in order to attract policy attention. Currently, it is unclear whether this group introduces a pro-CCS bias in the information on CCS. On the one hand, it is easy to see how these individuals would have a collective interest to underestimate the reported costs of applying CCS, leading to a bias in the information provision (similar to what one might see in other mitigation options). On the

41 Based on IPCC (2005).
42 IPCC (2005).
43 IPCC (2005).
44 IEA (2004) and IEA (2006) etc.
45 DNV (2007). Identified gaps within thematic areas of CCS. Jason Anderson, Heleen de Coninck, Paul Curnow, Todd Flach, Heleen Groenenberg, Christopher Norton, David Reiner, Simon Shackley, Gudmundur Sigurthorsson. DNV – BRINO912OFLA070115-1: Oslo, Norway.

other, a recent survey[46] indicated increasing support for CCS with time spent on working on CCS issues, but a threshold effect whereby at about 50% time on CCS, support for the option grows only slowly. This suggests that those closest to the issue might actually be some what more critical and aware of uncertainties than those involved more at a distance, e.g. in a higher management capacity.

– Technological and cost risks: Before new technologies such as CCS can be implemented, corporate decision-makers need to find a way to incorporate technological and policy risks in their investment decisions. This inevitably takes time and requires confidence in the option to be pursued. Although in some quarters belief in CCS is growing rapidly, the risks of seepage are still uncertain, as well as the cost consequences of scaling CO_2 capture to a full-fledged power plant.
– Interactions: Although awareness of climate change is increasing, there is uncertainty about the future shape of climate policy, both on the national and the international level. Although all mitigation options are dependent on future developments in policymaking, the deployment of CCS depends on them even more, because there are so few co-benefits (in fields such as air quality or energy security of supply) associated with implementing CCS.

The information problems resulting from these cost uncertainties proliferate in the estimates of the role CCS would play in the future energy system. As a rule, system modelling yields results surrounded by uncertainty, as it incorporates uncertainties from various system components as well as inherent uncertainties in the model and the system itself. An example of such uncertainties in the model design and assumptions is how information is dealt with. The model will decide for investment in CCS if the benefits exceed the costs, but in reality, investment decisions depend on more complex (risk) factor balancing.[47] The consequences of this can also be seen in modelling of CCS economics.

Economic estimates for the mitigation costs of CCS have been quoted for the last fifteen years. Bottom-up estimates of 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.[48] However, this potential is very uncertain, as illustrated by the recent abandonment of the Tjeldbergodden project in Norway because the project commerciality depended on incremental oil recovery from CO_2-EOR, which appears to be too small. A sizable investment in feasibility studies and reservoir exploration had been made.

Generally speaking, however, because of the estimated nature of bottom-up costs, and the estimates that can be made based on comparable operations, engineering costs are fairly reliable.

The question is whether top-down economic studies, often used as a basis for policymaking, use those estimates. This can be verified by comparing the estimates resulting from bottom-up engineer information to the cost input data for top-down models. Input values for the costs of CCS in top-down models have not been reported directly in the literature, and transparency in this field could be enhanced. However, the assumed costs can be deduced from a comparison of CCS deployment in the model and the associated CO_2 prices. 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\$/tCO_2 is zero, and in 2035, when the price is 11 US\$/tCO_2, about 300 $MtCO_2$ per year. In the MiniCAM model[49], at a marginal carbon price of only 2 US\$/tCO_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\$/tCO_2, and deployment reaches over 3 $GtCO_2$ per year[50]. This is summarised in Table 3.

46 Shackley, S., H. Waterman, P. Godfroij et al., (2007): Stakeholder perceptions of CO_2 capture and storage in Europe: Results of the EU-funded ACCSEPT survey. Available on www.accsept.org, consulted August 13th, 2007.

47 Blyth, W. (2006): Factoring risk into investment decisions. UK Energy Research Centre Working Paper: UKERC/WP/TPA/2007/007.

48 IPCC (2005).

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

50 Current CO_2 prices vary greatly. In the EU Emissions Trading Scheme, prices around 30 US\$/tCO_2-eq have been reported. In projects for the Clean Development Mechanism, prices are more around 5 to 10 US\$/tCO_2-eq. In the voluntary United States Chicago Climate Exchange, prices are between 1 and 2 US\$/tCO_2-eq.

Table 4: 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).

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 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) is 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. *(see Table 4)*

The extent to which this also applies to other models is unclear, as the cost input data are generally not in the public domain.

IV. Discussion of main challenges for CCS

Although CCS is often pictured as a mature technology, it has problems in terms of social acceptance and economic robustness. The regulatory consistency within the EU is not yet established, but many of the legal challenges to CCS are likely to be addressed with the recent acceleration of efforts in the European Commission. Plans for a consistent EU regulatory framework, including policy incentives for demonstrations, through the ETS and potentially other instruments are being made and considered.

The progress on the regulatory front, however, cannot conceal that problems pertain in other fields. Lack of transparency and information leads to a number of risks that can be contemplated specifically in the context of CCS, although they may not be unique to CCS. The evidence of CCS costs, and the economic modelling work, is currently not complete and suffers from fundamental information and conceptual problems. This leads to economic risks in terms of the cost/revenue structure of single CCS projects, but also to political risks related to the overall costs of ambitious policy to pursue CCS.

The efforts of the EU to fill many legal and regulatory gaps would reduce political risks for project developers and solve some cost uncertainties along the way. They, however, do not resolve the question of socio-technical risks, related to how ever the slightest risk of leakage from CO_2 storage reservoirs is viewed by the public. Social acceptance remains uncertain as it is difficult to assess the lay public opinion on CCS as long as people have not yet formed one, and the number of studies is limited. However, it is likely to depend on the position of environmental organisations on CCS. In order to make CCS acceptable for the lay public as well as sceptical governments, more research into understanding of non-technical aspects of acceptability, and the particular dynamics influencing acceptability, is required.

From the above, we identify three wider issues that consistently present themselves as pre-eminent in the CCS debate. First, there is the issue of aligning technical certainties and uncertainties regarding safety and liability of underground storage with the lay public's technological risk comfort zone. The nuclear energy case has clearly demonstrated that social acceptance is not only brought about through sound technical data and risk assessment, but is at least partly driven by perceptions of trust in institutions and "stigma", attached to a particular technology These aspects should be exposed more clearly for CCS, in order to enable the complex adaptive system of social acceptance to proceed.

This relates to the second issue, which pertains to the CCS in the CDM debate. This was initially discussed in a purely technical matter (is CO_2 storage permanent?), but that approach has not yielded a workable solution. Identifying the norms, convictions and interests behind the positions might clarify what could become ingredients of a future solution to this issue.

Finally, independent of the sustainability, policy instrumentation, or the social acceptance of CCS, the question arises whether CCS damages the potential of renewable energy to play a more dominant role in the energy system – which is a deep wish of environmental organisations and several governments. Delving into this question, from various perspectives and approaches, could provide practical policy solutions.