The EU funded ACCSEPT project:

Identified gaps within thematic areas of CCS

Deliverable D3.2 from ACCSEPT – Identified gaps Intermediary report from ACCSEPT

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Summary:

This report is an intermediary report in ACCSEPT that identifies gaps within legal, regulatory, economic, social field and cross-cutting issues. Important parts of the earlier work in ACCSEPT are earlier on summarised in a literature review report, a report from the first stakeholder workshop and a survey report covering the questionnaire survey and the findings from it.

The working method for this report takes into consideration external sources as well as earlier internal work in the project. Gap lists have been developed through this and discussions in the group. First by identifying gaps, later on by prioritising among the identified gaps. In addition one has discussed how the relevant gaps relate to gaps in other areas, this can be seen as an initial phase of the cross-thematic analysis coming later in the project.

Findings from this report will be used further in ACCSEPT to analyse how identified gaps can be filled and thereby contribute to moving towards the desired situation for the carbon capture and storage (CCS) framework.

3-5 identified gaps have been prioritised for each of the different themes (legal, regulatory, economic, social field and cross-cutting issues).

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1 EXECUTIVE SUMMARY

The identified gaps that have been prioritised for the five themes – legal, regulatory, social, economic and cross-cutting issues – are listed below.

Prioritised gaps on legal issues:

- **Clear interpretation of international treaties**. The London Convention 1972 addressed issues related to CCS in late 2006. Other relevant treaties where greater clarity is needed are UNCLOS, UNFCCC, Kyoto Protocol and OSPAR.
- **Liability.** Different questions have been raised including: identity of the public or private entity liable, limited or unlimited liability, liability for what kind of damages and how long responsibility should last.
- **Legal Rights.** Nature of property rights in stored gases, reservoir and surroundings and nature of surface/subsurface property rights (Different ownership regimes in the US **(sub-**soil is private) and Europe (pore space is owned by the State and utilised under licenses))**.** Management of related property rights is also an issue.
- **Relationship between CCS activities and EU Directives.** Relevant EU Directives are in the areas of water/ waste/ landfill/ pollution/ Environmental Impact Assessment and none currently address CCS specifically.

Prioritised gaps on regulatory issues:

- **Framework that links site selection, management, closure and post-closure best practices** (as are currently being developed in research and pilot plants) to regulatory criteria.
- **Establishing the link between monitoring technology and levels of certainty required under regulation**: which technologies will meet requirements, and in which combination.
- **EIA/ SEA criteria.** These needs to be developed and tested.
- **A methodology for inclusion in the EU ETS.** Link between CO_2 from covered facilities (easier to account annually) and CO_2 in geological sites – this may be deferred to separate regulation and not in the ETS legislation itself.
- **Appropriate levels of action.** What should be achieved at EU level, and what at Member State level? Which bits of current legislation might be altered, or what might be needed?

Prioritised gaps on social field issues:

- **Better geographic coverage and time evolution of public attitudes.** Both focus groups (qualitative) and opinion polls (quantitative) are either absent (in most countries) or scarce.
- **Interaction between awareness and perceptions of climate change and energy policy upon support for CCS**. There is little work looking into how (or if) knowledge of CCS influences public acceptance.
- **Effectiveness of different types of educational materials, methods of communication and messengers**. It will matter significantly in what context CCS is placed and described when it is communicated. Moreover, most materials are currently only available in English.
- **Case studies of public reaction to actual storage sites are lacking**. Relevant places to start could include early movers such as Ketzin in Berlin and Norway. Cross-country studies are also absent.

Prioritised gaps on economic issues:

- **Impact of high upfront (capital) costs on investment**. The capital required upfront for investments in capture is large and involves significant uncertainties. Industries may therefore be reluctant to embark on CCS projects, even as the carbon price rises. Factors that impact decision-making of investors are unclear and cost estimates not transparent.
- **The cost-effectiveness of developing the CO_2 transport infrastructure is an economic as well as a regulatory gap in knowledge**. Depending on the modality of CCS deployment, it might be more cost-effective if the EU or a combination of member states would manage the large investments in an EU-wide network.
- **Provisions for interim support for CCS to bridge the uncertainty gap in the ETS**. Such provisions – probably on the Member State level – would be necessary if immediate deployment of CCS is deemed desirable. Low current prices and uncertainty post-2012 are barriers to CCS deployment
- **The use of CCS in the CDM is a regulatory gap as well as an economic gap in knowledge**. If the potential for CCS under the CDM is very large this will have a depressing impact on the CER price, and hence on the EUA price. If it proves too difficult to get credits within the CDM, interest in CCS in developing countries will be reduced.

Prioritised gaps on cross-cutting issues:

- **It is unclear how CCS can contribute to timely transition to large-scale renewable energy systems**. Application of CCS requires more fossil fuels be used to produce the same amount of end-user products, but higher prices for fossil generation will make alternative sources more competitive.
- **There is a general lack of "best practices" for many crucial elements in the overall CCS value chain.** This limits the effectiveness of implementation of CCS. Another result is that the overall scalability of CCS is poorly understood.
- C**ompeting uses of the same pore space in the underground**. It is unknown what the possible conflicts of use mean for CCS and what limits the mutually exclusive use of the underground imply for other desirable activities
- **Fossil fuel power plants involve externalities across the entire lifecycle many of which CCS will not solve/account for.** This could be surface mining of coal, transport of coal by rail and ship, air quality issues related to these and other. It is unclear how non-climate externalities will impact the acceptability of CCS.

2 INTRODUCTION

This report is an intermediary report in ACCSEPT. It identifies gaps within the different thematic areas described in the project. The thematic areas covered are legal, regulatory, economic, social and cross-cutting issues. Improving the knowledge base of these issue areas will contribute to bringing Europe from the current situation to a desired situation for the CCS framework.

The working method builds on external sources as well as work done as part of the ACCSEPT project. The IPCC Special Report on CCS (IPCC, 2005), and different IEA studies (IEA, 2004; IEA, 2006) has been of great value in addition to input from other European projects funded from FP6 (i.e. CO2ReMoVe, CO2SINK, CO2net). Important parts of the earlier work in ACCSEPT are summarised in a literature review report, a report from the first stakeholder workshop and a survey report covering the questionnaire survey and the findings from it. The literature review provided a relevant overview of work being done in the area (ECN, 2006[1]).

The first stakeholder workshop (April 2006) gathered 15-20 selected experts that shared their knowledge and opinions to update the image from the literature review and in addition contribute to broaden the image of how implementation of CCS can and will emerge. A major stakeholder survey was conducted in late 2006, and its report analysed input from a broader group (more than 500 respondents) and further extends the knowledge base for the ACCSEPT work (Shackley et al., 2007[2]). Gap lists have been developed through this and discussions in the partner group, first by identifying gaps, later on by prioritising among the identified gaps. In addition, relevant gaps have been related to gaps in other areas, as can be seen as an initial phase of the cross-thematic analysis due later in the project.

Findings from this report will be used further in ACCSEPT to analyse how identified gaps can be filled and thereby contribute to moving towards the desired situation for the CCS framework. The next report (D4.1) in ACCSEPT will include a cross-thematic gap analysis. The identified gaps will be narrowed to a smaller number which can be addressed in more detail in this project, bearing in mind that other ongoing efforts (e.g. of other EU research projects, national and industry research) are well advanced in certain of these issues and should not be duplicated. Later in the year ACCSEPT will present recommendations from the project to the European Commission.

[1] Coninck, H., Groenenberg, H., Anderson, J., Curnow, P., Flach, T., Flagstad, O., Norton, C., Reiner, D., Shackley, S. (2006).
[2] Simon Shackley, Holly Waterman, Per Godfroij, David Reiner, Jason Anderson, Kathy Draxlbauer, Heleen de Coninck, Heleen Groenenberg, Todd Flach and Ole Flagstad (2007).

3 LEGAL ISSUES AROUND CCS IN PUBLIC INTERNATIONAL AND EU LAW

There are a wide range of unresolved legal and regulatory issues that need to be resolved in order to carry out CCS activities. Four themes which are the focus of the present Technical Report are issues arising under public international law, Liability, Legal rights around property and the applicability of EU Directives.

Public International Law

From an international law perspective, this report will concentrate on legal barriers to the effective development of CCS in light of existing international regimes. Many of the international covenants and EU directives 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. Some of the challenging international law issues are considered below. 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. 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.

United Nations Convention on Law of the Sea (UNCLOS)

United Nations Convention on Law of the Sea (UNCLOS) 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. UNCLOS extends the sovereignty of a coastal State to 12 nautical miles, known as the territorial sea. It also recognizes an exclusive economic zone with a 200 mile limit from the same baselines used to measure the territorial sea for conservation and management duties. Although UNCLOS is expressed as applying to the seabed and its subsoil, it may be possible that it would also apply to CCS activities *beneath* the subsoil. 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.

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. It is necessary to clarify whether CCS falls within the definition of "pollution" in light of the view 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.[3]

United Nations Climate Change Convention (UNFCCC)

A third issue is how the United Nations Framework Convention on Climate Change and its Kyoto Protocol will consider CCS as a device giving rise to emissions reductions credits. The UNFCCC requires the compilation of a national inventory of ‘emissions by sources’ and ‘removals by sinks’ of all greenhouse gases, using comparable methodologies agreed by the Parties. Parties must also report on policies and measures and their impacts on emissions by sources and removals by sinks. It is not clear how CO_2 captured and stored in geological repositories would be reported under existing UNFCCC reporting requirements. Article 1.8 of the UNFCCC defines ‘sink’ as ‘any process, activity or mechanism which removes a greenhouse gas, an aerosol or precursor of a greenhouse gas from the atmosphere.’ ‘Source’ is defined as any process or activity which releases a greenhouse gas, an aerosol or a precursor of a greenhouse gas into the atmosphere.’

The Convention also defines ‘reservoir’ as a component of the climate system where a greenhouse gas is or a precursor of a greenhouse gas is stored.’ Reporting may be challenging where leakage rates from storage sites are unknown, where geological storage sites combine CO_2 from a variety of installations, or for a variety of purposes (e.g. disposal, storage, enhanced oil recovery), or where these sites extend beyond national borders. Clarification is needed on how captured and stored CO_2 relates to ‘emissions by sources’ and to ‘removals by sinks. Emission factors for individual geological storage sites may need to be developed. The Kyoto Protocol permits emissions trading between Annex I Parties, where a Party has not exceeded its full assigned amount for a given commitment period. The

[3] IEA Greenhouse Gas R&D Programme (2003).

relationship of CO_2 capture and storage to present and future Kyoto commitments and to emissions trading under the Kyoto Protocol requires substantial discussion and clarification. At COP/MOP 1 it was decided that further consideration of the relationship between the CDM and CCS was necessary. [Status of IPCC Good Practice Guideline - Inventories]. Finally, the legal regime around incentives needs to be addressed. This is important in encouraging the use of CCS activities within the EU, in particular how to incorporate into the EU ETS.

The London Convention 1972 and 1996 Protocol.

On November 2 2006, a legal gap was identified and addressed under the London Convention 1972 and its 1996 Protocol ("London Protocol").The London Protocol, which replaced the London Convention expressly prohibits the deliberate disposal (dumping) into the 'sea' of wastes from vessels or manmade platforms. 'Sea' is defined broadly to include the 'seabed and subsoil thereof', but not to include 'sub-seabed repositories accessed only by land.' The 'reverse list' under the London Protocol, which lists substances which may be conditionally dumped under strict control, includes "COS streams from CO2 capture processes" from 10 February 2007. However, dumping of CO2 streams may only be considered for dumping if:

- disposal is into a sub-seabed geological formation;
- the stream consists overwhelmingly of carbon dioxide; and
- no wastes or other matter are added for the purpose of disposing of those wastes or other matter.

Convention for the Protection of the Marine Environment of the North-East Atlantic (OSPAR Convention)

The OSPAR Convention was 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 OSPAR Convention regulates pollution in the marine environment using different approaches for different sources of pollution (pollution from land-based sources, pollution by dumping, and pollution from off-shore sources – oil and gas activities). As a result, the same wastes, matter, or substances, with the same effects on the marine environment, may be regulated differently under different OSPAR Annexes depending upon how those wastes, matter or substances reach the marine environment. In addition, OSPAR looks to the purpose for which wastes or other matter may be placed in the maritime area. Different purposes are regulated differently, though they may have the same environmental impact.

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.[4]

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.

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[4] OSPAR (2004).

Their report outlines some legal issues which have an impact on the implementation of CCS activities:

- Land-based sources: For example, Annex I *permits* the deliberate disposal under the seabed of pollution from land-based sources, with land-based sources defined to include 'sources associated with any deliberate disposal under the sea-bed made accessible from land by tunnel, pipeline or other means and sources associated with man-made structures placed in the maritime area . . . other than for the purpose of offshore activities', *but* must be strictly regulated or authorised. Under the OSPAR Convention, where land-based sources are involved and deliberate disposal under the sea-bed is contemplated, Parties must: require use of best available technology (BAT) for point sources, including clean technology where appropriate; require best environmental practice (BEP) for point sources, including where appropriate clean technology; create a system for monitoring and inspection for compliance with regulations or permits; and undertake other initiatives. These elements and systems may need to be established for pollution from land-based sources in the context of CCS activities.
- Dumping from vessels: Under Annex II, the 'dumping' of CO_2 (wastes and other matter) in the seabed and its subsoil from vessels and man-made structures at sea is *prohibited*, though exceptions exist for 'placement' for certain purposes (e.g. 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. These Annexes should be reviewed toward a common approach for CO2 that addresses similar risks, purposes and wastes similarly, either across the three Annexes or through a new Annex, in order to increase regulatory certainty.

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.

Several aspects of in situ liability under CCS 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 EU Environmental Liability Directive* places strict liability on 'operators' for the prevention and remediation of environmental damage to protected species, natural habitats, water or land resulting from a range of listed 'occupational activities. However, further analysis is needed to clarify:

- Which and when CCS activities fall within these occupational activities (e.g., is CO2 considered a 'waste'? is a geological storage site a 'landfill'?)

- Whether strict liability would apply in respect of damage to land, water or biodiversity caused by "dangerous activities"
- Whether CCS activities would fall within non-dangerous activities, in which case liability attaches to the person or entity exercising control over the relevant activity.

The EU Environmental Liability Directive provides for certain exonerations from liability, including where an emission or event is authorized by permit. The gap analysis paper will consider whether permits could be developed for CCS activities. These permits would need to address various conditions in order to minimise the risk of environmental damage.

However, some liability issues surrounding CCS activities are not addressed by any EU legislation. For example, there are challenges arise around the long timeframe of carbon storage and the risk of leakage. The gap analysis paper will consider some of the legal considerations necessary to properly address this legal shortfall in EU law. It is possible that international liability regimes may be relevant here to the capture, transport and storage of CO_2.

For example, the HNS Convention (not yet in force) addresses liability for damages from a pollution incident involving the transport by vessel of liquefied gases in bulk by ship. The Watercourses and Industrial Accidents Protocol on civil liability (not yet in force) addresses the transboundary effects of industrial accidents. The Basel Liability Protocol (not yet in force) addresses liability and compensation for damage resulting from the transboundary movement and disposal of hazardous wastes and other wastes and clarifies who will be responsible for compensation in the event of an accident.

Legal Rights

There are a number of other legal rights relevant to CCS activities which will need to be addressed by EU law.

One example of this is property rights, specifically the nature of surface and subsurface property rights. Clarity here is necessary in order to provide certainty to project proponents and governments of their entitlements and obligations if they carry out CCS activities. 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. Conversely, in Europe, pore space is owned by the State and utilisation is addressed in the licensing process. 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[5]:

- 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?

[5] Intergovernmental Panel on Climate Change (2005).

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.[6] 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.

Other issues relating to legal rights exist around intellectual property rights. This is a particular concern in relation to capture technology (as opposed to transport and storage technologies). There is a concern that risks exist around technology transfer to developing countries.

Finally, it will also be necessary to clarify what obligations exist on monitoring, reporting and verification of CCS activities and leakage. Also, there may be authorisations or permits for activities implicated by CCS. This might include emissions from industrial installations, waste disposal operations, transportation of waste, land filling of waste. The gap analysis will provide further detail on whether more detailed EU law is required in this respect.

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 (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).

It will be necessary to clarify whether CO_2 is "waste" under EU law. *The EU Waste Framework Directive's* broad definition of 'waste' excludes from its scope 'gaseous effluents emitted into the atmosphere.' However, CO_2 that is not 'emitted into the atmosphere' but instead captured prior to emission, and intended for disposal, would seem to fall within the Waste Framework Directive's regulatory scope. If captured CO_2 is regulated as 'waste', establishments or undertakings carrying out waste disposal or recovery operations related to CO_2 will require permits under Articles 9 and 10 with appropriate conditions. The regulation of CO_2 as 'waste' impacts the treatment of captured CO_2 under other Directives that rely on the definitions of waste under the Waste Framework, among them the Landfill Directive. This will have significant consequences for environmental law provisions around environmental impact assessment, remediation, planning and development considerations such as site selection, injection operation and monitoring plans. It will also affect the liability of private actors and States in relation to regulating the protection of vulnerable resources such as drinking water, protected habitats, populated areas and petroleum resources.

The EU Landfill Directive bans the landfilling of 'liquid waste.' CO_2 is most likely to be injected into geological cavities in liquid form. At least one Court, evaluating the disposal of liquid waste by injection into a borehole 1000 meters or so below sea level has found this activity covered by the Landfill Directive, and the injection of liquid waste prohibited. Hence the physical state in which CO_2

[6] Carbon Sequestration Leadership Forum (2004).

is ‘accepted’ at a landfill, and the physical state of CO_2 at injection are likely to impact its treatment under current legislative frameworks.

The EU Water Framework Directive allows Member States to authorise the injection of ‘water containing substances resulting from the operations for exploration and extraction of hydrocarbons . . . into geological formations from which hydrocarbons or other substances have been extracted or into geological formations that are unsuitable for other purposes.’ (Art. 11(3)(j)). It also permits Member States to authorise injection of natural gas or liquefied petroleum gas into geological formations, which are permanently unsuitable for other purposes, or to inject natural gas or LPG for storage purposes in certain circumstances (Art. 11(3)(j)). The Water Framework Directive contains no explicit reference to CO_2. The relationship between the Landfill Directive and the Water Framework Directive warrants consideration in the context of CO_2 storage.

The EU Monitoring Guidelines define ‘installation’ as a stationary technical unit and any other directly associated activities which have a technical connection with the activities carried out on that site and which could have an effect on emissions and pollution, as defined in the Directive’. It is not clear under whether or under what circumstances the boundaries of an ‘installation’ for a particular activity could extend to related geological storage activities.

Prioritised gaps on legal issues:

- **Interpretation of international treaties**. The London Convention 1972 that addressed issues late in 2006. Other relevant treaties are UNCLOS, UNFCCC, Kyoto Protocol and OSPAR.
- **Liability.** Different questions are raised; public or private liable entity, limited or unlimited liability, liability for what kind of damages and how long should responsibility last.
- **Legal Rights.** Nature of property rights in stored gases, reservoir and surroundings and nature of surface/subsurface property rights (Different ownership regimes in the US **(sub-**soil is private) and Europe (pore space is owned by the State and utilised under licenses))**.** Management of related property rights is also an issue.
- **Relationship between CCS activities and EU Directives.** Relevant EU Directives are in the areas of water/ waste/ landfill/ pollution/ Environmental Impact Assessment

4 REGULATORY GAPS

In identifying current gaps in regulation, we have drawn on our work with stakeholders and a literature review. Here we present insights from stakeholders, an outline of gaps and a list of specific gaps to be considered for the ACCSEPT project

Outcomes of our research indicate that stakeholders and public opinion have valuable insights for regulation priorities (note that incentives are discussed in the economic section of this report, and broader legal issues in the legal section):

Policy has to put CCS into the context of a mitigation portfolio, but be aware of non-climate priorities. Renewable energy may have other qualities that make them preferable to CCS, while CCS may have other aspects that make them less desirable despite CO_2 benefits (the same is true of nuclear, though much more emphatically, in terms of public opinion).

In other words, CCS policy can not be done absent considering other policies or it will probably not be viewed as credible, nor will it gain enthusiastic backing of the public, as opposed to mere acceptance.

Given the early stage of CCS development, any regulations should ensure high public confidence so there is no sense among the public that an ‘unknown and untested’ technology is being pushed on them. For regulation this entails:

a. Good public communication requirements
b. An attempt at clarity in requirements despite the difficulty of pining down specific criteria given site variability, etc.
c. if power is vested in a local authority for site approvals, EIAs, etc., there should be a link to national and international policy and regulation that ensure local decisions are in line with broader expectations and that local authorities have the best insight and expertise being brought to bear on the issue.

Legislation should focus primarily on storage, as capture and transportation are more conventional business practices, and legislation is largely already in place.

There are questions regarding storage and leakage, including 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.

Site selection and associated certification requirements should be clear and strict, because it may reduce monitoring requirements, cut down on the amount of remediation that might be needed in the event of failure (i.e. if not sited under a populated area, less population exposure can be anticipated, etc.), and give some more certainty to regulators of long-term performance, which could have implications on future re-licensing, etc.

While the concept of ‘leakage rates’ is intuitively attractive, in reality sites are unlikely to leak in a steady and easily measurable fashion (if they do leak). Regulatory requirements can not feasibly use such a rate concept in their requirements.

Local HSE requirements will be important in reinforcing avoidance of primarily short-term high-volume leakage: while many HSE requirements already exist, they will have to be adjusted and expanded in light of new CCS activities. Long-term and potentially low-level leakage which returns CO_2 to the atmosphere should ideally be avoided through proper site selection and management, though this is not a guarantee. Attempting to account for leakage through the carbon market (debits, discounts), terms of liability, etc. are outside the scope of site regulations but some mechanism would have to be covered through a broader scheme.

Environmental impact assessment is an important part of project development, and Strategic Impact Assessment is a tool growing in importance to place projects in a broader context of strategic priorities. At the moment there are no guidelines for completing EIAs and SEAs. The practical implication is that, as EIAs in particular are in general required for any project, there is a potential bottleneck to the approvals process pending guidelines.

Based on these insights from stakeholders and study of the literature, the following gaps have been identified:

Prioritised gaps on regulatory issues:

- **Framework that links site selection, management, closure and post-closure best practices** (as are currently being developed in research and pilot plants) to regulatory criteria.
- **Establishing the link between monitoring technology and levels of certainty required under regulation**: which technologies will meet requirements, and in which combination.
- **EIA/ SEA criteria.** These needs to be developed and tested.
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- **Appropriate levels of action.** What should be achieved at EU level, and what at Member State level? Which bits of current legislation might be altered, or what might be needed?

5 SOCIAL FIELD GAPS

Despite the fact that some first studies have been done on public perceptions towards carbon capture and storage technologies, 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" (Hill in HoC, 2006). In part, this is because these 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.

Any "social" gap analysis is intimately linked to the other areas covered in this gap analysis (e.g. a reliable legal and regulatory framework is likely to enhance public acceptance, as well as for instance trust in institutions). Nevertheless, it is still possible to focus on questions of public awareness, knowledge and preferences as distinct from the other areas.

Other critical questions that might be elucidated by studies of social acceptability include the messenger and the form of the message, i.e., who presents the case for CCS and how it is presented. To date, most of the outreach on CCS has been conducted by oil and gas firms, the electric power sector, and to a lesser extent, government agencies. Studies of credibility have found, however, that these groups are precisely those least trusted by the general public (Eurobarometer, 2005). Those considered most trusted are environmental groups and independent scientists. The most common source of information on general questions of energy and environment are the news media, most importantly television followed by news media.

Local and national environmental groups constitute an important shaping influence upon public opinion, particularly at a stage where the public itself lacks information. Hence, engaging stakeholders in a discussion of CCS is an important element in any effort to determine social acceptability. There have been some efforts by governments and industries to engage with key stakeholders, but such efforts are not always appreciated. In testimony before the CCS Inquiry of the House of Commons Committee on Science and Technology, NGOs in the UK were critical of existing government and industry efforts (HoC, 2006, 42).

On the monitoring of public opinion, consider first the question of public opinion polls. One obvious gap is the lack of geographical coverage across the EU-25. There have been only a small handful of nationally representative opinion surveys. Even in those few European countries where studies have been carried out, the earliest surveys only date to 2005. Thus, it is necessary to monitor the time evolution of public attitudes responding to ongoing developments. One might expect that given the early stage in the development of CCS and the implementation of the first projects that there is considerable scope for public awareness to grow and for attitudes to shift.

The first polls were conducted in the UK and Sweden by the University of Cambridge and Chalmers University of Technology working together with the Massachusetts Institute of Technology and under the auspices of the Alliance for Global Sustainability (Reiner et al., 2006). More recently there have been surveys completed in Spain by Ciemat and in France by CIRED. A recent Eurobarometer (2007) study asked the first question across the EU-25 on public awareness of both "clean coal" and "carbon capture and storage". Although there have been some informal efforts to coordinate amongst academic researchers, there is no mechanism or funding for coordination in terms of timing, the language used in questions or the survey instrument employed. Thus, **there is no programme for the regular**

monitoring of public opinion in any one country let alone the EU-25 as a whole and, to date, no single comprehensive survey across the EU-25.

Greater effort needs to go into understanding differences across demographic subgroups. It is well known, for example, that women are far less supportive of nuclear power then men, but the demographics of public attitudes on CCS is largely absent.

Aside from the more quantitative, representative studies there have been very few qualitative studies such as focus group work or interviews with laypeople (Shackley, McLachlan, and Gough, 2005; Huijts, 2004). **Aside from independent qualitative national studies, which are a necessary first step, it is important to understand cultural and cross-national differences by carrying out identical studies in several different European countries**.

Around the world, different groups such as CCP, CSLF, UNEP, IPCC and various national governments and multinational firms have put together a range of different types of educational materials and methods of communication, and many more are examining the possibility of developing such materials. There has been incidental consultation across projects, but no sustained effort to coordinate these many different activities. **To date, education and dissemination activities have all been carried out independently and there have been no studies of the effectiveness of different forms of educational materials.**

A number of firms including Statoil, Vattenfall, BP, Total and other firms have engaged in project development, development of promotional materials and community outreach as part of their current or planned projects. Although there may have been some internal corporate efforts to assess these projects, **there are no case studies of these first novel projects including developing an understanding of response from the community as well as from the local, national and international media.**

The eventual acceptance of CCS as part of a portfolio of options would logically seem to depend on the awareness and perceptions of CCS as well as the perceived urgency and challenge of addressing climate change more broadly. Unlike other measures such as energy efficiency or renewables, which might have other sources of support, CCS is entirely linked to climate change. Assuming tough carbon constraints, then the next level of discussion is with regard to how CCS is perceived in comparison with other low and zero-carbon technologies such as renewables, nuclear power, and to some extent, natural gas. CCS will therefore be affected by the level of concern over energy security, climate change and price and its relation to other generation technologies, but **there have been no serious studies of how CCS fits within the broader energy, environmental, economic, equity and security context.**

There are a wide range of siting problems that firms or governments encounter when trying to cite a new facility ranging from a high-level nuclear waste storage facility and incinerators to municipal landfills or solid waste facilities and new factories. There has been no work to determine whether CCS is perceived as an industrial process or as a decision that draws broader national level attention akin to the case of nuclear power. Determining where on spectrum of siting of different types of facilities CCS falls would require greater familiarity with the technology and so should be studied as part of the first projects. Indeed, **there is little clarity as to even which stage of the process (capture, or more likely, transport or storage) is likely to elicit greater opposition and what could explain the sources of that opposition**.

Apart from siting issues associated with storage and transport, the broadest implications of CCS might well be the impact that CCS will have on electricity prices. Recent Eurobarometer studies (2006,

2007) have found relatively low willingness to pay for renewable energy. If CCS is perceived as being responsible for rises in consumer electricity bills, then one might expect that CCS will be perceived more negatively. On the other hand, there were quite large differences in willingness to pay between countries and this may be related in part to the rate of GDP growth and to the unemployment rate.

There has been some work on the costs of other low-carbon sources such nuclear power and renewables which has implications for CCS. In part, the perceived impact of costs may depend on the manner in which CCS is introduced. For example, a subsidy for capital construction is different from a guaranteed feed-in price, which itself is different from a low-carbon fossil fuel obligation. **There have been no studies of how the public will view the different mechanisms to incentivise CCS. To our knowledge only two surveys (the ACCSEPT survey and the UKCCSC survey of Gough et al.) have asked stakeholders about their perceptions of** different incentive mechanisms CCS.

Another serious gap is the complete absence of data in certain countries and the lack of information regarding CCS in many languages. The Summary for Policy Makers of the IPCC Special Report on Carbon Capture and Storage was translated into the major languages of the United Nations (i.e., French, Spanish, Russian, Chinese and Arabic). In addition, there are several sources of more popular information on CCS including various industry consortia and governmental organisations including the United Nations Environment Program (UNEP), the Carbon Sequestration Leadership Forum (CSLF), International Petroleum Industry Environmental Conservation Association (IPIECA) and the CO_2 Capture Project (CCP). Specific projects in individual countries such as Germany and France have begun to see the development of materials in those languages. CO_2-Net East is also providing material for stakeholders in various Eastern European languages, building in part upon the translations that were conducted for the ACCSEPT project. Nevertheless, **virtually all the material is developed in English and the first materials are only slowly being developed or translated into other key European languages**.

A more basic question is whether public perception itself is relevant to the development of CCS. There is evidence that many NGOs, for example, do not believe that the public has a well-articulated view or the organisation that could influence the technology development process[7]. **The relationship between public acceptability and adoption of a technology by the political process has not been adequately explored.**

Although research into public perception does not by itself enhance social acceptance it does serve as an important first step towards understanding potential concerns of members of the public and other interested parties. Studies of public perception can also provide insight in the strategies that can best be followed to design risk assessment and regulatory schemes which are less likely to provoke public hostility. Other examples of the introduction of new technologies can also provide useful analogues with respect to public and stakeholder perceptions and their management. Examples include biotechnology and renewable energies. In the case of biotechnology, institutional innovations have been adopted such as advisory panels and regulatory committees with wide membership, i.e. not just technical experts but members with moral, philosophical and sociological expertise to bring to the debate. Citizens' Panels and Juries are a further example of institutional innovation, whereby members of the lay public have been brought directly into detailed discussions of the control of, e.g. genetically modified organisms and nanotechnologies. To the surprise of many renewable energy developers, public opposition has on occasions been intense and this has resulted in numerous initiatives attempting to create a more participatory approach to renewable energy planning. It is unclear,

[7] Shackley, S. and McLachlan, C. (2006).

however, whether such innovations would be adopted without a groundswell of public opposition or scepticism.

Given the absence of adequate study it should not be surprising, but **there is no mechanism by which studies of public acceptability might inform regulatory design.**

Prioritised gaps on social field issues:

- **Better geographic coverage and time evolution of public attitudes.** Focus groups (qualitative) and opinion polls (quantitative) are relevant measures here.
- **Interaction between awareness and perceptions of climate change and energy policy upon support for CCS**. There is a lack of work looking into how (or if) knowledge on CCS influences acceptance in the public.
- **Effectiveness of different types of educational materials, methods of communication and messengers**. Today most information material is only available in English. It will matter significantly in what context CCS is placed and described when it is communicated.
- **Case studies of public reaction to actual storage sites are lacking**. Relevant places to start could be Berlin and Norway. Cross-country studies are also lacking.

6 ECONOMIC GAPS

Costs and economics of CCS determine to a large extent the decision-making, both by policymakers and by corporate entities, on CCS projects. Numerous studies on CCS and costs exist in the peer-reviewed literature, and economic modelling has been carried out with various models, and the present state of affairs is comprehensively assessed in the IPCC Special Report on CCS (IPCC, 2005), and in a number of IEA studies (IEA, 2004; IEA, 2006). However, the wealth of information hides 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:

- 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 that are not developed in the hands of academic researchers, who tend to publish early results in journals, but further developed by corporate entities that are bound by commercial interests and hence secrecy. Many of the specifics of technologies and cost data are therefore not fully available, and the correctness of assumptions on that 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 unconditionally promoting the options, in order to attract policy attention. These individuals have a collective interest to underestimate the costs of applying CCS, leading to a bias in the information provision.
- 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 takes time and faith in the option to be pursued. Although we seem to have arrived at a point when confidence is CCS is growing rapidly, risks of seepage are still uncertain, as well as the cost consequences of scaling CO_2 capture to a full-fledged power plant.
- Interactions: In the field of climate change, but of all mitigation options (with the exception of nuclear) probably even more so in the field of CCS, there is uncertainty on future developments. These policy and legal developments will to a large extent determine the future costs of CCS.

Gaps in economic and cost knowledge around CCS have been identified on a number of occasions. In the report that was the result of WP2, a number of gaps in the field of CCS was identified. The stakeholder workshop also identified a number of them. In the meantime, also work has been undertaken by various institutes that resolve some of the issues (see e.g. Uyterlinde et al., 2006) and also that raise issues. A non-exhaustive list of gaps is summarised here:

- 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. Some of these questions have been resolved in a recent report (Uyterlinde et al., 2006).

- 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 and operational costs, as well as on the nature of the sector (risk-averse or risk-seeking). The capital required upfront for investments in capture is large. This may tend to keep industries from embarking on CCS projects.
- The cost-effectiveness of the means of realising the CO_2 transport infrastructure is an economic as well as a regulatory gap in knowledge. Depending on the pathway of CCS deployment, it might be more cost-effective if the EU or a combination of member states would manage the large investments in an EU-wide network. For instance, a CO_2-intensive country such as Belgium with very limited CO_2 storage capacity might make use of storage capacity in the Netherlands or Germany. In that way, also Belgium would be able to reduce CO_2 emissions in a more cost-effective manner. However, if the implementation of the infrastructure of CO_2 transport is left to the private sector or to the member states, it is unlikely that the EU-optimum for the infrastructure will be chosen. An integrated study in this field remains to be done.
- Because of remaining uncertainty about post-2012 incentives, but even because of the low near-term prices, it is questionable whether the EU Emissions Trading Scheme is sufficient as the sole support for the first commercial projects. Provisions for interim support for CCS to bridge the uncertainty gap in the ETS – probably on the Member State level – would be necessary if immediate deployment of CCS is deemed desirable.
- The use of CDM is still a regulatory gap, but also an economic gap in knowledge. If the potential for CCS under the CDM is very large, for instance because very cheap projects can go ahead in the gas processing industry and these will flood the market, this will have a depressing impact on the CER price, and hence on the EUA price. This would inhibit the implementation of other mitigation options in the EU. 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.
- 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 costs, timing, feasibility and acceptability. There are still questions remaining about the most cost-effective means of getting different technologies into the portfolio – e.g. efficiency maybe best through standards, not the market, while for others a clear carbon price is sufficient.
- The transaction costs of CCS might be an economic liability. The realization of integrated CCS projects necessitates a coordination of efforts of the fossil fuel industry, the electricity sector, and possibly other parties responsible for CO_2 transportation. Such cooperation will increase transaction costs, and will add to the financial uncertainty in CCS projects.
- Underground spatial planning on the basis of economics is a largely unexplored field. For saline formations, the competition of "functions" of underground space will be less relevant, but for depleted gas fields that can be used for strategic reserves of natural gas, for compressed air-energy storage to cope with intermittency of renewable energy sources, and CO_2 storage, may be a relevant issue.
- Regulatory requirements for CO_2 storage projects may be significant, and may add to the cost of monitoring an underground CO_2 storage location. The relation between monitoring costs and regulatory requirements is largely unexplored.

- 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.
- Storage-ready power plants are currently poorly defined, and their costs have not been explored in detail; there is not even consensus on what a storage-ready power plant is. The optimal time for applying CCS (early to prevent a major restructuring later on, or later during refurbishment when CO_2 market prices make it worthwhile?) is unclear at this point.

Prioritised gaps on economic issues:

- **High upfront (capital) costs**. The capital required upfront for investments in capture is large and with high uncertainties. This may tend to keep industries from embarking on CCS projects, even with high carbon prices. Factors that impact decision-making of investors are unclear and cost estimates not transparent.
- **The cost-effectiveness of the means of realising the CO_2 transport infrastructure** is an economic as well as a regulatory gap in knowledge. Depending on the pathway of CCS deployment, it might be more cost-effective if the EU or a combination of member states would manage the large investments in a EU-wide network.
- **Provisions for interim support for CCS to bridge the uncertainty gap in the ETS –** probably on the Member State level – would be necessary if immediate deployment of CCS is deemed desirable. Low current prices and uncertainty post 2012 are barriers to CCS deployment
- **The use of CDM is a regulatory gap as well as an economic gap in knowledge**. If the potential for CCS under the CDM is very large this will have a depressing impact on the CER price, and hence on the EUA price.

7 CROSS-CUTTING ISSUES GAPS

The gaps identified under this heading include the CCS issues that overlap (or in some cases fall completely outside of all other categories) the other thematic areas. This relates to the role of CCS in the overall energy supply, inherent limits to capacity building outside of the framework of economics and social acceptance, etc. Many of these gaps are knowledge gaps that can potentially be filled by increased efforts into fit-for-purpose studies, which in turn would serve as input into policy-making processes.

- **It is unclear how CCS can contribute to timely transition to large-scale renewable energy systems.** The ultimate goal of energy policy is to ensure reliability, availability and environmental sustainability of the primary sources of energy and resulting carriers. Although CCS can contribute to the environmental sustainability of fossil fuels, it does not change the basic resource limits from nature. In fact, application of CCS requires that more fossil fuels be used to produce the same amount of end-user products. Renewable energy is therefore promoted to ultimately solve both the environmental challenges and resource reliability and availability limits. Thus many have concluded that resources that are applied to CCS cannot be simultaneously applied to renewable energy development, so CCS is considered as a direct competitor to renewable energy development.
- This conclusion hides the fact that production of renewable energy systems requires large inputs of energy, which is often provided by fossil fuels. E.g. steel for wind turbines is produced in steel mills that use coal. Purifying of silicon ore to the level required for photovoltaic cells (99.99999% purity) is another example. This suggests that if a minimum amount of fossil fuel energy is applied to creating renewable energy systems, components, etc., that ultimately increase the overall share of renewable energy production in the whole energy market, then in fact CCS can contribute to the timely transition to large-scale renewable energy development, and the whole debate about the technology lock-in trap that CCS poses is moot. The gap then is how to mandate such dedication of CCS energy supply to production of renewable energy systems, and link this to specific goals of renewable energy content in the energy market.
- The recent paper by Viebahn et al. (Internal Journal of Greenhouse Gas control, 1: 121-133) addresses the LCA issues for CCS versus renewables in Germany and discusses in general roles of CCS v. renewables.
- **There is a general lack of "Best Practices" for many crucial elements in the overall CCS value chain. This limits the effectiveness of implementation of CCS. Another result is that the overall scalability of CCS is poorly understood due to the separate Best Practice issues of lack of confidence in geological storage, limited future availability of fossil fuels, and absolute effectiveness of full scale implementation of CCS in a highly carbon-constrained world.**
    - ***The first example mentioned concerns practices related to estimating the long-term, regional geological storage capacity at the necessary level of confidence.*** Regional geological storage capacity estimates are strictly pore space inventories of the underground with little or no filtering for the trapping ability of cap rocks or the degree to which such are compromised by faulting, fracturing or other geologic features that "short-circuit" deep reservoirs to the surface. These issues will only be handled on a

site-by-site basis under a specific project planning and permitting framework. One example of how the lack of a Best Practice for geological storage capacity estimations is for the Utsira formation in the North Sea. One conservative estimate of geologic storage capacity (Holloway et al, 2006) includes the structural traps in the Utsira only, and estimates total storage capacity to be about 1.2 Gt. The operator of the Sleipner CO_2 storage facility, however, claims that the Utsira can hold about 500 Gt of CO_2. This claim has been referred to in an EU internal communication (European Commission, 2006). These two estimates are clearly incompatible, and are a direct expression of the lack of a recognized Best Practice for this task.

- ***The second practice is related to practices concerning estimates of the future availability of fossil fuels, and whether they will be attractive enough to justify large investment in CCS technology and systems. Is there basis for 1, 2, 3 or more generations of new power plants with CCS?*** The currently experienced limited availability of conventional natural gas and oil pose serious threats to EU energy security. However, coal is still locally available in significant quantities within EU member states, and can in addition be sourced from a world market that still lacks an effective cartel of coal producers. The most recent estimate of coal resource lifetime is 180 years at a constant 2005 consumption rate[8]. This same source projects however that "…coal consumption increases by 3.0 percent per year on average from 2003 to 2015, then slows to an average annual increase of 2.0 percent annually from 2015 to 2030.", which translates into an a more realistic lifetime of world coal resources of 70 years. If world coal consumption continues to grow at a rate of 2-3% yearly, consumers may experience the same problems of availability of coal at some point in time, similar to the way that markets are observing for natural gas and oil today. China is currently closing a large number of smaller coal mines that are considered unsafe, and is in fact importing coal in the short term to compensate (Nakanishi, 2007). It is unclear if this is a long-term trend for Chinese coal production. What is known is that China builds a new coal-fired power plant about once weekly, and that this will probably continue for at least 2-4 years. The question is therefore how long coal will be perceived as a plentiful resource at reasonable prices and availability for the next 40-70 years, a necessary minimum for the lifetime of typical coal power plants. The only way to answer this is to apply recognised Best Practices to data collection and analysis for coal, oil and natural gas resources in a an improved way relative to what the current suppliers of such deliver. If resource availability can only accommodate 1-2 generations of new CCS plants, then policy makers should consider alternatives to CCS to not only avoid high investments in new technologies that have a short life cycle[9], but to invest in and transition to more sustainable energy systems as early as possible.
- ***The third Best Practice relates to the accounting and forecasting of net absolute CO_2 emissions from the entire value chain and life cycle of CCS projects. If CCS systems can only deliver partial reduction of greenhouse gas emissions, will this ultimately be sufficient for goals of climate stabilisation?*** The absolute effectiveness of CCS in

[8] See http://www.eia.doe.gov/oiaf/ieo/index.html. Report #:DOE/EIA-0484(2006)
Release Date: June 2006, Chapter 5: World Coal Markets

[9] This situation was experienced in North America in the period 1995-2004 when a large number of new-build NGCC plants were unable to obtain reasonably priced natural gas. See for example "National Gasification Strategy: Gasification of Coal & Biomass as a Domestic Gas Supply Option", William G. Rosenberg, Michael R. Walker and Dwight C. Alpern, Harvard University John F. Kennedy School of Government, January 2005.

terms of emissions of greenhouse gases is dependent on the capture solutions applied. Post-combustion solutions can expect 70-90% emissions avoidance, i.e. they still release 20-30% of their produced CO_2 to the atmosphere, relative to a similar reference plant without CCS. This will probably be the case for all post-combustion capture plants installed as retrofits, which is the business case for many power plant operators with coal-powered plants already running. Other solutions may provide close to 100% capture, e.g. new-build Greenfield oxy-fuel combustion. In a situation with extremely low limits on greenhouse gas emissions, e.g. maximum 2 Gigatons CO_2 from all global sources in year 2100, a world with a large and growing CCS system based largely on post-combustion retrofits that do not capture all emissions may be unable to satisfy such strict limits.

- **It is unclear what the time scales of full implementation of CCS are for different scenarios of required mitigation, and if the implementation of CCS will progress fast enough.**
- Current projections of CCS development show that very few projects will be realised in the next 15 years. Many Greenfield fossil fuel power plants are planned for the next 15 years under the premise that they can be retrofitted with CCS when required, thus these will in fact increase emissions in the next 15 years as long as they are not replacing similar older fossil fuel power plants. This timescale of retrofitting may be too slow for the more dramatic scenarios of climate change. Can CCS application be effectively accelerated to have a positive impact in the pessimistic climate change scenario? What would be required to achieve this? This suggests a set of gaps for the "accelerated" case. In a scenario of "accelerated" CCS implementation, will industry be forced to replace capital equipment faster than planned? Interaction of timescales of learning, replacement economics will be important.
- A big question here is whether a forced or accelerated programme of energy efficiency improvements with tight carbon emission quotas would be more effective than CCS? E.g. governments could impose new requirements and standards upon homeowners, car and appliance manufacturers, airlines, etc. In general consumer goods turn over much more quickly and are of much lower capital cost than power plants. Alternatively, big renewable energy projects could be considered, e.g. tidal barrage. (The River Severn barrage could supply 10% of UK's electricity for example). Finding systematic way of comparing these different options would be v. valuable but also complicated.
- **There are competing uses of the same pore space in the underground. It is unknown what the possible conflicts of use mean for CCS and what limits the mutually exclusive use of the underground imply for other desirable activities.**
- CO_2 geological storage will compete with two other uses of the same pore space in the underground (seasonal natural gas storage and compressed air storage for load following energy storage for electricity production).
- An example of competing use of the underground is already documented. In 2006, a site was being considered in Germany by an energy company for geological storage of CO_2 to be captured from a future power plant. The site was subsequently acquired for seasonal natural gas storage by an operator of natural gas distribution networks, and the developer of the CCS project was forced to consider other sites and write off data collection and analysis invested in the primary site.

- The other competing use is underground storage of compressed air. Currently there only exists one such facility in Europe (Huntorf, Germany, operated by E.ON), but there is reason to believe that more will follow. Underground compressed air energy storage is interesting for two applications. Firstly intermittent energy sources, primarily wind turbines, need to store energy because they produce at times when electricity demand is low, and do not produce when energy demand is high, i.e. they are “non-dispatchable” and must rely on other system components to smooth production in line with electricity demand. The second interesting application of underground compressed air energy storage is for base-load electricity facilities that produce excess energy at certain times of the day, e.g. at night when energy demand is at a minimum.
- In the case of wind turbines, if they are to provide an ever larger share of the total electricity production given their intermittent non-dispatchable profile, the only solution for stabile operation of the electricity grid is include more storage that allows greater flexibility to smooth electricity production in line with consumption. The gap here is to forecast (uncertain) growth of wind turbine electricity production, and estimate the need for energy storage, and how much of this should be provided by underground compressed air (other solutions for energy storage must be considered as well).
- An additional consideration is the optimum use of power plants with CCS. These must necessarily be “base-load” plants, i.e. that they are operated at constant, high capacity (95+%) with as few disruptions as possible. In other words, they will not be used in “dispatch” to follow the daily and seasonal swings in end-user electricity demand due to temperature and the needs for lighting. The implication is that traditional “peaking” plants that can be turned on and off on short notice and can run on partial load will not have CO_2 capture, because they operate at less than 20% capacity overall (some at 10%), and investment in a CO_2 capture plant would hardly be attractive for such low capacity factors. The driving factor would then be to minimise the amount of electricity generated using “peaking” fossil fuel power plants without CCS. Note that peaking fossil fuel plants also operate at lower efficiencies (high heat rate) because they must run at sub-optimal conditions in order to deliver flexible output.
- An interesting link here is to consider that underground compressed air energy storage works by delivering compressed air (40-80 bar) to a modified natural gas turbine (open cycle), which can then run at much higher efficiencies than otherwise because they need not use energy in the compression stage of the turbine. Whereas an open-cycle natural gas turbine can achieve 25-35% efficiency in dispatchable operation, a natural gas turbine running on compressed air can achieve 60-70% efficiency, even when operating in dispatchable mode.
- **Fossil fuel power plants will have other externalities for their whole value chain that CCS will not solve, and these are still poorly accounted for, such that the relative value of CCS compared to competing alternatives is poorly understood.** Examples are surface mining of coal, transport of coal by rail and ship, air quality issues related to these (IIASA with GAINS), extra system coal use due to the parasitic load of CCS and related increase in transport needs, pressure on local water consumption from steam reforming or gasification processes applied in pre-combustion CO_2 capture solutions, pressures on local water usage by post-combustion amine scrubbing units, etc.

Prioritised gaps on cross-cutting issues:

- **It is unclear how CCS can contribute to timely transition to large-scale renewable energy systems**. Application of CCS requires more fossil fuels be used to produce the same amount of end-user products.
- **There is a general lack of "best practices" for many crucial elements in the overall CCS value chain.** This limits the effectiveness of implementation of CCS. Another result is that the overall scalability of CCS is poorly understood
- C**ompeting uses of the same pore space in the underground**. It is unknown what the possible conflicts of use mean for CCS and what limits the mutually exclusive use of the underground imply for other desirable activities
- **Fossil fuel power plants will have externalities for their whole value chain that CCS will not solve/account for.** This could be surface mining of coal, transport of coal by rail and ship, air quality issues related to these and other. The relative value of CCS compared to competing alternatives is poorly understood due to this.

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