ENVIRONMENTAL ASSESSMENT FOR CO_2 CAPTURE AND STORAGE

Technical Study

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INTERNATIONAL ENERGY AGENCY

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Background to the Study

An earlier study has explored how well the permitting systems of a number of countries would apply to Carbon Dioxide Capture and Storage (CCS) projects. One of the key findings was that Environmental Impact Assessment (EIA) was likely to play a key role during the permitting process. EIA is a structured process of scoping out and evaluating the environmental impacts of major projects and formulating appropriate measures to manage and mitigate them. This study was commissioned to explore in more detail the role of EIA for CCS projects and in particular to evaluate

- the adequacy of existing EIA frameworks,
- the extent to which existing legislation would mandate its application to CCS,
- the degree to which the necessary expertise and information is available to carry out effective assessments.

The study was also framed to assess the likely impact of trends in the use of environmental assessment which has in recent years seen the emergence of Strategic and Cumulative assessments as well as broadening of the scope of individual assessments. Strategic Environmental Assessment (SEA) adopts a similar structured approach to EIA but aims to assist in policy and regulatory decisions relating to implementation of multiple projects.

Approach

The study was tendered and awarded to Det Norske Veritas, London office. The first step was to identify the range of EIA frameworks in existence and to map out these frame works so that they could be compared. This was done by drawing up a list of all the steps which are included in the EIA process and checking each frame work to assess how thoroughly it covered each step. This enabled a chart to be drawn up which highlighted where particular frameworks might be deficient. In total 13 frameworks for EIA were analysed, most being National Frameworks but with several used by International organisations. The extent to which each Framework was complemented by an SEA process was also mapped out and an assessment of each of the main steps required for a full SEA was also analysed.

The next step was to consider how well the frameworks would handle Carbon Dioxide Capture and Storage, including whether EIA would be triggered by the associated legislation.

The final step was to consider the information needs for carrying out an EIA or SEA. These relate largely to information on the effects of CO_2 releases in various situations on such things as flora, fauna, water resources, land use, human population, as well as the range of other environmental disturbances caused by implementation of major industrial undertakings.

Results and Discussion

Thirteen EIA/SEA frameworks were identified for comparison and analysis. These were 10 country and 3 international frameworks as listed below:-

Country frameworks

- Australia
- Canada
- EU (Applies to EU countries)
- France
- Germany

- Japan
- Netherlands
- Norway
- UK
- USA

International frameworks

- IAIA (International Association for Impact Assessment)
- IFC (International Finance Corporation)
- UNECE (United Nations Economic Commission for Europe)

The process of conducting an EIA follows a sequence of key steps and current best practice is considered to consist of 15 steps as listed below. Not all frameworks cover all of these steps. The analysis of the frameworks was carried out against this set of steps and the activities which should occur during them. These are elaborated further in the main report.

Main steps in the EIA process:-

- Screening
- Scoping
- Analysis of alternative options
- Project description
- Environmental baseline review
- Legislative review
- Impact identification
- Impact prediction
- Impact significance
- Impact mitigation
- Environmental management plan
- Environmental monitoring programme
- Reporting
- Review
- Project implementation and operation

Key findings are that, as might be expected, all the methodologies are similar. However some elements of the best practice EIA methodology are not required by law. Also some countries may have other legal requirements which trigger some form of environmental assessment or consideration. However changes to correct any deficiencies detected through analysis of the documentation should be considered in the light of national feedback on how EIA and SEA have actually been working in practice

CCS projects are not specifically mentioned in EIA & SEA frameworks mainly because the technology is new. The report recommends that to create regulatory certainty the existing legislation pertaining to EIA & SEA is either adapted or separate specific legislation is introduced to encompass CCS.

When considering best practice for EIA applied to CCS projects it was found that many of the frameworks would need amendment to meet minimum requirements for acceptance by Kyoto mechanisms such as CDM and JI (Clean Development Mechanism and Joint Implementation). Also CCS EIA requirements are likely to be defined for the EU-ETS (European Emissions Trading System) and in IPCC 2006 guidelines.

International guidelines for ESHIA for CCS projects

The report writers considered the general needs for environmental impact assessment for CCS projects and concluded that there would be great benefit in developing a single international guideline. Some reasons for this conclusion are the international nature of CCS, the prospect that it will be applied in countries without strong regulation or EIA methodologies, the likelihood of its execution under Kyoto mechanisms and the probability of injection into geological structures underlying international waters. They also considered that because of the acute risks posed by leakage of CO_2 to Health and Safety that the process should cover these aspects too. This combined process is termed ESHIA (Environmental, Safety and Health Impact Assessment). The report makes this recommendation and lists 10 features which should be incorporated into such an international methodology. In brief these are:

1) Include Health and Safety aspects
2) Use risk based approach with modelling for releases
3) Exclude high risk projects
4) Incorporate a full carbon balance
5) Include detailed guidance and on each of the ESHIA steps
6) Specify environmental resources to be covered and minimum information requirements
7) Include binding commitments for monitoring, management and site handover to authorities
8) Include guidance on long term liability management
9) Have separate ESHIA at time of abandonment to ensure current best practice is applied
10) Include the results of a Storage Performance Assessment (SPA)

Information needs and gaps

The report goes on to consider what gaps exist which would need to be filled to enable an ESHIA meeting the proposed international requirements to be carried out effectively. The most significant gaps identified were in the areas of:-

- Quantifying impacts from CO_2 release – probability estimates
- Conducting Site Performance Assessment (SPA)
- Understanding the environmental and health impacts of CO_2 release and impurities
- Managing liability
- Balancing positive climate change mitigation impacts against negative local impacts

Quantifying impacts from CO_2 release – probability estimates

At present the analysis of the risks of leakage from an underground storage reservoir are difficult to quantify because there is little historical data available from such operations. The number of demonstrations of storage around the world is rapidly increasing and information from these projects will help to fill this gap. Also the techniques for identifying leakage paths and assessing their integrity are still under development. Furthermore the gathering of the best information about deep geological formations itself requires the drilling of exploratory wells which may create far greater risks of leakage via abandoned well bores than any already present.

Conducting Site Performance Assessment (SPA)
There is a clear need for guidance on the minimum standards and methods to be used for assessing the performance of a potential storage reservoir. These must include:-

- Mapping of the reservoir and establishing the baseline conditions
- Identifying the potential leakage paths
- Modelling the expected progress and fate of the CO_2 plume
- Modelling uncertainty in the underground

Taking each of these in turn:- While 3D seismic and well coring is being used extensively in demonstration projects these techniques are expensive and for commercial storage, where the emphasis is not on conducting scientific investigation or acquiring data, there will inevitably be pressure to do only what is absolutely necessary. Hence the perceived need for minimum standards

Imaging techniques to find potential leakage paths rely on complex manipulation of data and the experience of specialist staff. It is difficult to prescribe how this is done which will be a challenge to those formulating the guidance.

One of the challenges of predictive modelling is considered to be obtaining a sufficiently fine grid for simulating CO_2 flow and fluid movements in the reservoir.

Techniques for modelling uncertainty in relation to safety have largely been developed for assessing equipment and operations on the surface. Another suite of techniques has been used for assessing uncertainty in the underground but with somewhat different objectives i.e. the probability of finding hydrocarbons or valuable mineral deposits. These traditional tools may not be sufficient.

Understanding the environmental and health impacts of CO_2 release and impurities

There are two elements to this subject. The first is to understand how leaks either on shore or offshore would spread and disperse through the environment, which in the case of leaks from storage includes the shallow subsurface. The second is to understand the effects on flora and fauna as well as human populations. There are considerable gaps in the knowledge of effects on the marine environment both on specific organisms but also on ecosystems. One effect of CO_2 release is acidification and the effects of this on marine ecology is a young science.

Onshore there is a certain amount of knowledge about the effects of CO_2 on animals and vegetation. Effects on smaller organisms are less well researched. Human health effects are well understood but effects on less healthy members of the population less so.
Effects on species can form valuable indicators which can be used for monitoring purposes. More needs to be done to understand and measure effects and select suitable indicator species.

Managing liability

Handling of long term liabilities is an issue which becomes relevant during the environmental management plan formulation and project implementation and operation steps in EIA. Provisions for handling the long term liability issue thus need to be developed. The report considers several options and outlines two in particular for consideration:

- Permitting Authority responsible for closure sets performance criteria which would trigger cessation of liabilities by site operator.
- International scientific advisory panel established to monitor long term integrity and most importantly to administer a liability fund.

The first option implies that responsibility ultimately reverts to Government which is something which might require legislative changes in some jurisdictions or might not be aceptable. The second option has the advantage of enabling liability to be shared between a wide range of projects and thus reduce the cost while at the same time ensuring ready availability of cash to take remedial or restorative measures. However providing cover for the liability in this non-competitive way may be more expensive than other options.

Several other options involving long term liability of project operators, discounting emission reduction certificates, use of temporary certificates (as noted in IETA paper 7/2/06) are also mentioned but are generally less favoured as they may inhibit project developers.

Balancing positive climate change mitigation impacts against negative local impacts

The report concludes that guidance on the play off in priorities between local pollution concerns and climate change needs to be developed. It also notes that this balance is likely to shift with time as the amount of CO_2 stored underground increases and also as experience with leakage risks accumulates.

Another feature of the balance is accounting for the long term impact of "sterilising" reservoirs and the overlying land for certain types of development. This could have either positive of negative effects on environmental resources in the long term.

Expert Reviewers' Comments

A number of constructive comments were received as a result of which the section dealing with knowledge gaps, particularly for marine systems was strengthened and additional references added. One reviewer expressed concern about including a carbon balance as part of the proposed ESHIA process particularly where CCS was combined with enhanced hydrocarbon production. This is a critical issue in relation to projects generating certificates under Kyoto CDM, and to a lesser extent JI, mechanisms. However because EIA, and particularly SEA, have to consider global impacts unrestricted by artificial project boundaries, this recommendation to include a carbon balance is retained. The extent to which monitoring and verification should become legally binding was also raised. The report was amended to reflect the fact that commitments of this nature do typically become legally binding as a result of the permitting processes which accompany the finalisation of an EIA.

It was suggested that the proposals for scoping of EIA were too much based on characterisation of risks rather than environmental resources and the text was modified to reflect this. It was also pointed out that the comparison of EIA/SEA frameworks took no account of the practical application which sometimes adequately fills the perceived gaps. Notes were added to the effect that the actual effectiveness in a particular jurisdiction should be checked before considering making any changes. Some reviewers felt that the differences between EIA and SEA were not clear and the report was modified too make this clearer.

In general reviewers found the contents of the report useful and reasonably comprehensive. Many other suggestions were made, all were reviewed and the majority resulted in some changes by the authors.

Major Conclusions

Because CCS is a new technology existing EIA/SEA frameworks are not tailored to cover a number of its essential requirements. It is possible that in practice they would be interpreted or extended to do so but this is by no means certain. It is a main conclusion that ESHIA should be a requirement of all CCS projects and that it would be worthwhile to develop an internationally accepted framework. This could then be used by countries with weak or non-existent EIA/SEA frameworks when they undertake CCS projects. Countries or organisations with a proven framework could refer to the international framework when considering adaptations of their own frameworks to cover CCS.

There are gaps in knowledge about the effects of CO_2 on land and particularly marine environments. Further research is needed in these areas. Guidance on how to address the balance between local environmental effects and long term and global climate change effects is needed. Further, when such guidance is developed, it will need to be updated as experience with CCS is gained and the volumes of stored CO_2 mount.

Assignment of long term liabilities and provision of financial cover remains a key issue. Liability is expected to be addressed when finalising EIA in the context of granting permits for CCS. Whilst the report puts forwards some proposals it is clear that much further work has to be done to resolve this.

Recommendations

It is recommended that the IEAGHG:-

1. Promote development of an international framework for EIA/SEA for CCS projects and that this could in the first instance be based on that currently used by the IFC which should be encouraged to retain “ownership”. Alternatively, because CCS is so specific to climate change, promotion of ownership by the UNFCCC could be considered.

2. Promote development of guidance or best practice for the trade off between global climate change impacts and local environmental impacts of CCS projects with due consideration of the long time scales involved. Such guidance would need to be developed by specialists with experience of conducting EIA but would need to be adopted by the International community. Consequently a suitable “owner” for the finalised guidance should be sought.

3. In order to co-ordinate scientific research on impact prediction of CO_2 releases consideration should be given to establishing a new IEAGHG network on this theme.

4. Promote further dialogue with operators, regulators and the insurance industry on the issue of long term liability for CCS projects.

Environmental Assessment for CO_2 Capture and Storage:

report for IEA GHG R&D Programme
Rev 3, 19 December 2006

MANAGING RISK DNV

Environmental Assessment for CO_2 Capture and Storage

for

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EXECUTIVE SUMMARY

Introduction

Background

Current science indicates that there is a link between climate change and human burning of fossil fuels which release greenhouse gases such as carbon dioxide (CO_2). The gases are believed to trap the heat generated from incoming solar radiation, causing an increase in global temperature. This increasing temperature is understood to result in potentially significant regional changes in climate, such as increased intense storm frequency, drought and sea level rise.

Scientists believe that levels of the greenhouse gases carbon dioxide and methane in the atmosphere are higher now than at any time in the past 650,000 years.

Carbon (dioxide) Capture and Storage (CCS) is one of the techniques that scientists believe could play a significant role in reducing the accumulation of emission of greenhouse gases into the earth's atmosphere. CCS refers to the process of capturing CO_2 from large point sources such as power plants and storing it in deep geological reservoirs, instead of releasing it into the atmosphere.

DNV have been commissioned by the International Energy Agency Greenhouse Gas R&D Programme (IEA GHG R&D) to undertake this study, in which the Environmental Impact Assessment (EIA) methodology that will be required for CCS projects is considered.

Objectives

The objective of this study is to review current EIA and SEA frameworks for use with CCS for the purposes of:

- Determining the degree to which existing frameworks need to be adapted for CCS projects and how these improvements should best be made.
- Reviewing future trends and developments in EIA and SEA.
- Assessing information requirements and knowledge gaps for conducting EIA of CCS projects, and suggesting research needed to develop the techniques to successfully conduct CCS impact assessments.

Carbon dioxide Capture and Storage - CCS

The Intergovernmental Panel on Climate Change (IPCC) defines 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". CCS is proposed as an attempt to mitigate the effects of released CO_2 on the atmosphere thus stabilising atmospheric greenhouse gas concentrations.

CCS involves three stages: capture, transport and storage. The capturing of carbon dioxide generated by fossil fuel combustion is done by separating CO_2 from the flue gas either prior to fuel combustion or post combustion. There are a range of capture technologies at different stages of development with some of the technology having been used in the petroleum and gas industry for a significant period of time.

CO_2 is captured as a gas and transported as a liquid either by tanker or pipeline to its injection point. In order to prevent the CO_2 re-entering the atmosphere and causing GHG warming, it must be stored in reservoirs for hundreds to thousands of years. It can be stored both onshore in terrestrial geological structures and offshore in sub-seabed geological structures. There are three main options for storage of CO_2 in geological formations:

- Deep saline aquifers (on or offshore)
- Depleted or near-depleted oil and gas fields
- Unmineable coal seams.

Additionally, further CCS options such as ocean storage and mineral carbonation exist, but these options are in the very early phases of development, and geological storage is currently considered more technically and economically feasible. Ocean storage is considered highly controversial and is generally not considered as environmentally viable.

Review of EIA and SEA Frameworks

The main objectives in the framework review were to determine:

- What a common best practice EIA framework would look like.
- The degree to which existing frameworks would need adapting for CCS projects to meet EIA best practice, and how such changes can be made.

Best Practice Environmental Assessment framework

A comparative review approach was used to help identify best international EIA practice and to develop a single common EIA framework that would be internationally applicable to CCS projects.

EIA and SEA frameworks from around the world were examined by mapping against key stages in the DNV EIA process methodology. The DNV EIA process methodology is based on the International Finance Corporation (IFC) guidelines combined with best practice identified from Countries where DNV operates. Elements that would add value to an international EIA framework for CCS and could be considered as "good practice" were identified and combined. The result was the formulation of a best practice EIA framework.

General Findings

Gaps in SEA & EIA legislation

By mapping EIA and SEA frameworks from around the world against key stages in the DNV EIA process methodology, existing gaps in the frameworks were highlighted.

It was found that the main stages of EIA and SEA from countries around the world are similar, but by no means the same. In many cases, some elements of good practice EIA are not actually required by law. This does not necessarily mean these elements do not take place, either as part of good practice, or as demanded by the regulator, just that they are not legally required. It can therefore be considered that there are general gaps in the EIA frameworks, although there may be no specific need to alter the country specific EIA/SEA regulatory frameworks in regard of such general differences, unless national feedback indicates that EIA and SEA has not been working in practice. Additionally, some countries may have legal requirements other than EIA and SEA that require some form of environmental assessment.

With regard to compliance with CCS best practice however, EIA frameworks may well require amendment to ensure that they meet the minimum requirements needed for acceptance by mechanisms such as the Clean Development Mechanism (CDM) and Joint Implementation (JI). CCS EIA requirements with specific terms are also likely to be defined under the EUETS CCS and IPPC 2006 guidelines. These specific requirements will also need to be considered for inclusion into EIA requirements as appropriate for local countries and the various mechanisms and schemes they will follow. .

DNV also examined the requirements of current EIA and SEA frameworks in various countries around the world in relation specifically to CCS projects.

CCS projects are not currently specifically mentioned in EIA & SEA frameworks because CCS is a relatively new technology. However, CCS projects may be captured under other industries covered by EIA /SEA legislation. In order to have regulatory certainty, it is recommended that, where appropriate, either existing legislation is adapted to ensure CCS is captured by EIA/SEA legislation or alternatively to develop a separate legislative framework specific to CCS. Studies are underway to resolve these regulatory issues in the EU. Ideally in local legislation there could be a requirement that for CCS projects, a SEA/EHSIA framework as defined in this document should be used. This would require minimal legislative work while ensuring a high standard of projects and EIA decision making.

With respect to SEA in Norway and Japan, no conclusions could be drawn because they have no SEA legislation or guidance frameworks at this point in time.

Overlap with other environmental legislation

To support the CCS concept, certain environmental legislation may also need amendment (in addition to EIA legislation), e.g. OSPAR, IPPC, Landfill Directive. Note that storage of CO_2 under the seabed will be allowed from 10 February 2007 under amendments to the London International Convention and Protocol, which governed dumping of wastes at sea. The OSPAR Convention, which provides further protection to the marine environment of North East Atlantic, is expected to follow suit.

Studies are underway to resolve these regulatory amendment issues, such that legislative barriers to CCS can be overcome without exposing the environment or people to unacceptable risk.

Capacity Building

Some developing countries may require institutional capacity building and support assistance to ensure full EIA specification and satisfactory review of the EIA is possible in all countries wishing to establish CCS activities. This assistance and capacity building could come from, for example, the establishment of a CCS Expert Panel (this could be set up under the Clean Development Mechanism (CDM) process for example). This expert panel would set out and disseminate industry best practices to support capacity-building in countries that feel they need assistance and support expertise in a new complex area of engineering endeavour. The expert panel would serve to enhance the robustness of CCS project development around the world.

EIA & Kyoto Protocol

CDM only requires an EIA if appropriate national law requires it. Given the complexity of the CCS projects and the reality that they are most likely to occur under Kyoto mechanisms, it is recommended that:

- Validation and Verification Manuals be updated to include specific requirement for an Environmental, Health and Safety Impact Assessment (EHSIA) in the validation of CCS projects, regardless of national requirements.
- National EIA schemes specify international EHSIA guidelines for CCS should be followed (although guidelines are not presently available).
- Align the requirements of CCS ESHIA with the requirements of CDM & JI.

Environmental Guidelines – General Issues

DNV recommends that international Environmental, Health and Safety Impact Assessment (EHSIA) guidelines for CCS projects be developed for the entire CCS chain, with particular focus on injection and storage. A framework for the environmental component of such guidelines is presented within the body of this report. It is recommended that the EHSIA assessment guidelines incorporate the following:

- In the case of CCS projects where a significant release of CO_2 could have an impact on health (e.g. onshore), an integrated ***Environmental, Health and Safety Impact Assessment (EHSIA)*** approach is recommended.
- Use an approach based on risk and *source-pathway-receptor* assessment and modelling.
- The identification and exclusion of projects with a high risk of not being completed or closed early. This would favour projects where the full environmental benefits of CCS can be realised.
- The development of a carbon balance for the whole project life cycle as part of the ESHIA process (possibly including the CO_2 value of incremental hydrocarbon from EOR) and only supporting projects with a significant carbon storage benefit.
- Detailed guidance covering all the typical EHSIA process steps.
- Identification of the environmental resources to be covered in an EHSIA, and the specific information that, as a minimum, should be included under each environmental resource based on the risks identified in this report.
- The EHSIA should require binding operator commitments for monitoring and management to specific standards, including post-closure monitoring and management and site handover for long term maintenance by competent authorities.
- Guidance for managing long term liability. If CCS projects are to be approved under the existing EHSIA frameworks, they need amendment because the liability for an operator will extend beyond the decommissioning of the project.
- For Nuclear projects, most countries/organisations demand a separate EHSIA for submission before nuclear installation operators receive approval to decommission and abandon a site. It is recommended that guidelines require the expansion of this concept to CCS storage, which will ensure Best Available Technique (BAT) is applied at the time of decommissioning.
- The EHSIA should include the results of the Storage Performance Assessment. It could be possible to set minimum requirements (via an expert panel) for best practice SPA in order to get a good practice EHSIA. As such, an implicit part of the ESHIA process will be site characterisation, performance assessment and risk analysis.

Specific Needs & Information Gaps

Information necessary to undertake EHSIA of the first two stages of CCS (capture and transport) is relatively well defined and does not have significantly different needs from the many impact assessments conducted every year. These two stages also do not involve technologies significantly different from those well established and in commercial use today.

Areas where further information is required include:

- Dispersion modelling of supercritical CO_2 releases from pipeline or reservoir – this is currently not well understood.
- Additional R&D is needed to improve knowledge of emerging concepts and technologies for CO_2 capture, in particular to help demonstrate the reliability of the environmental performance of capture systems on a large scale.

It is considered that the information necessary to undertake environmental assessments of the injection and storage of the CO_2 stage of a CCS project is not well defined, and has many uncertainties. The uncertainty relates primarily to the risk of CO_2 leakages, whether from faults, well blow outs, cap leaks, poor injection etc. In many cases the likelihood and size of such leaks is not currently well defined and the environmental impact they could pose is not clearly understood. Information gaps, needs and uncertainties are summarised below and in subsequent sub-sections, and expanded on in the main body of this report.

- There are currently no minimum national or international standards and requirements for site selection (storage reservoir) and it is recommended they be developed to include Geology, Seal Thickness and Integrity, Fluid Compatibility, Geochemistry/Geochemical reactions, Reservoir Properties Assessment, Disposal Well Selection, Well Modelling, Well design, primary cementing, materials quality, corrosion, monitoring, abandonment, failure of wells and pipelines etc. It should be noted that these generic standards will be limited in the level of protection they can achieve, because each individual CCS site will have different characteristics.
- Improved understanding of the proximity of major CO_2 sources to suitable storage sites to facilitate decision making about large scale deployment of CCS. Detailed regional assessments are required to evaluate how well large CO_2 emission sources match suitable storage options. This overlaps with SEA requirements.
- It should be clarified if pilot scale CCS developments require an EHSIA.
- Clear regulatory guidance on the play-off in priorities between local pollution concerns versus climate change concerns via some form of 'risk-benefit' approach is needed.
- SEA and EHSIA requirements and acceptance criteria need review at regular periods as knowledge improves.
- Clarity is required whether CO_2 emissions from the additional oil recovered as part of an Enhanced Oil Recovery (EOR) project would need to be assessed in an EHSIA for CDM.

Risk of CO_2 Release from Reservoir

Site Characterisation

Site characterisation exploration wells for baseline studies and pre-injection reservoir site approval will need to be minimised to avoid damaging the reservoir seal integrity. It is undesirable to pepper the ground with exploration wells, because it can reduce the integrity of the potential reservoir. However, a potential reservoir site with no existing site characterisation boreholes nearby will require the drilling of a small number exploration wells through the candidate site cap rock and the storage reservoir. The key is to understand the condition of the wells and then seal them appropriately. A strong, clear regulatory regime that is flexible enough to be site dependent needs to be developed.

Injection
More experience from CCS trials is required to increase confidence in using data from oil and gas EOR and storage injection wells.

Storage
Possible CO2 escape pathways are:

- Abandoned wells/wellbore failure
- Diffusion flow through caprock and leakage through potential faults
- Dissolution and lateral transport of CO_2 charged waters in the aquifer.

In general, there is restricted available quantitative data on probabilities and amounts of leakage from CO_2 geological reservoirs, although IPCC note that the fraction of CO_2 retained in *appropriately selected and managed geological reservoirs* is 'very likely' (probability 90-99%) to exceed 99% over 100 years & 'likely' (probability between 66-90%) to exceed 99% over 1,000 years (IPPC 2005).

The main difficulties for a quantified assessment of generic risks of CO_2 release from reservoirs are the lack of detailed long term monitoring of field trials or modelling done to date, and the fact that release risk is extremely site specific. However, closely related industrial experience and scientific knowledge (primarily from the oil and gas sector) could serve as a basis for appropriate risk management, although their effectiveness needs to be demonstrated for use with CCS. Consequently, the implementation of more pilot and demonstration CCS storage projects in a range of geological, geographical and economic settings is important to improve our understanding of the risk issues.

There are currently no guidelines available that provide a generic methodology to quantify probability and quantity of CO_2 release risk, and it is recommended that such a systematic methodology is developed, and that it considers issues such as:

- minimum lateral distances of populated areas from reservoirs;
- whether the following types of areas should be screened out or have their priority for CCS development downgraded:
  - areas with endangered/threatened species and sensitive sites
  - areas with low turnover lakes
  - areas with significant sources of groundwater located nearby
  - areas containing many old or abandoned wells.

Storage Performance Assessment
The risk assessment needs to incorporate the results of the Storage Performance Assessment (SPA) as an inherent part of the EHSIA. It could be possible to set minimum requirements (via an expert panel) for best practice SPA in order to get a good practice EHSIA. As such, an implicit part of the EHSIA process will be characterisation, performance assessment and risk analysis.

To support a good quality SPA, the following technical areas will need to be addressed as they are currently not fully understood, as discussed further in the main body of this report:

- Mapping the Underground: Clear minimum standards are required for comprehensive mapping of a reservoir and surrounding area during baseline data collection.

- Identifying Discrete Potential Leakage Paths in the Underground: it will be necessary to introduce a permitting regime capable of handling the limitations of automated seismic techniques.
- Grid of CO_2 Flow Simulators: it is a challenge to obtain the necessary resolution of predictive simulation reservoir models of dynamic CO_2 flow to adequately represent fluid movement.
- Modelling of Uncertainty in Leakage in the Underground: traditional tools for modelling uncertainty may be insufficient.

Environmental Issues

The following topics are also examined in this report to identify their specific needs and information gaps in order to be able to conduct a competent EIA:

- Modelling of CO_2 releases: Models are being developed to investigate CO_2 leaks to the marine environment, but further work is necessary.
- Effect on marine environment: Research shows that marine organisms and marine ecosystems, including coral reefs, can be detrimentally affected by ocean acidification. Current knowledge shows that any CO_2 leaks from CCS could have a significant impact upon marine organisms surrounding the leak. This reinforces the need to ensure that the risk of leakage from CCS is minimised through proper site selection, design and monitoring. Note there is also uncertainty about the impact upon the onshore water environment.
- Gaps in knowledge of the effects of ocean acidification upon marine ecology remain because this area of science is relatively young.
- Environmental criteria: Sound environmental criteria need to be developed.
- On-Shore Environmental Effects of CO_2 Exposure: Human health effects of CO_2 are well understood on healthy populations. Some knowledge gaps exist regarding the effect of CO_2 on plants, vegetation and ecosystems. The reaction of smaller organisms, specifically microbes, to CO_2 needs further research, in addition to clarifying the importance of microbes.
- Impurities: Better understanding of the impact of impurities in CO_2 is necessary.
- Monitoring of CO_2 Storage Projects: Although many monitoring technologies are mature, they have not all been demonstrated for CCS projects, and further development is necessary for less mature technologies. For example, very little is known about the use of changes in marine ecosystems or presence of indicator species to detect leakage of CO_2. Standard monitoring procedures and protocols require development.
- Remediation: Some remediation methods are well established, while others are more speculative. Additional detailed study is necessary to further assess the feasibility of applying these techniques to CCS projects.

Liability

Provision for handling long term liability needs to be developed, and below are some options for consideration, the practicalities of which need further examination:

- The authority responsible for issuing permit for closure could require post-closure stewardship and outline the criteria or performance requirements that would trigger cessation of liabilities for the site operator (ERM 2005).

- One option is that a scientific advisory panel under a central body be established for evaluating and monitoring storage integrity and administering a liability fund (long term).
  - This body would oversee and maintain a liability fund (part insurance, part investment) based on risk of leakage.
  - The individual contribution from each project to a central fund would be less than project specific funds because the risk is spread.
  - Using a specific CCS ESHIA methodology will allow comparable risk profiles.
  - The tax could be applied on value paid for CO_2 to operators throughout operation.
  - On hand over of liability, the fund could become part insurance and part investment.
  - This proposed mechanism also covers transboundary issues, operators storing CO_2 in same reservoir, migration of CO_2, as the international body will take on long term liability.
  - The central fund would have immediate access to cash to address any issues.

Other options for managing liability (IETA paper 7/2/06), are as follows:

- Creating longer-term liability for project developers/operators to buy GHG compliance units such as CERs in the event of seepage emissions as part of a CCS project approvals process (e.g. a permitting/licensing regime for CO_2 storage operations);
- Flagging CCS-specific CERs or issuing temporary CERs etc which would be cancelled and require replacement, *pro rata*, in the event of seepage. This would pass liability for seepage emissions on to the buyer of the CERs (“buyer liability”); or,
- Applying a default or discount factor to account for future seepage emissions so that either a portion of CERs are not issued, a portion are set aside in a credit reserve, or a portion of the revenue from CERs sales is set aside in a contingency fund. This could serve to essentially cap liability for all actors in the market at the chosen default or discount rate.

Whatever the approach, the most important consideration is that the structure of liability provisions needs to be practical and predictable for both project developers and the wider GHG market.

ABBREVIATIONS

BAT	Best Available Technique
BPM	Best Practicable Means
CCS	Carbon Dioxide Capture & Storage
CDM	Clean Development Mechanism
CSLF	Carbon Sequestration & Leadership Forum
CER	Certified Emission Reductions
CO2	Carbon Dioxide
DNV	Det Norske Veritas
DOE	Designated Operating Entity
EA	Environmental Assessment
EC	European Community
EGR	Enhanced Gas Recovery
EHSIA	Environment, Health and Safety Impact Assessment
EIA	Environmental Impact Assessment
EOR	Enhanced Oil Recovery
ETS	Emissions Trading Scheme
HIA	Health Impact Assessment
HSE	Health, Safety & Environment
IAIA	International Association for Impact Assessment
IEA GHG R&D	International Energy Agency Greenhouse Gas Research & Development Programme
IEMA	Institute of Environmental Management & Assessment
IET	International Emissions Trading
IETA	International Emissions Trading Association
IFC	International Finance Corporation
IPPC	Intergovernmental Panel on Climate Change
IPPC	Integrated Pollution Prevention & Control
JI	Joint Implementation
NGO	Non-Governmental Organisation
PDD	Project Design Document
SEA	Strategic Environment Assessment
SIA	Sustainability Impact Assessment
SPA	Storage Performance Assessment
TOR	Terms of Reference
UNECE	United Nations Economic Commission for Europe
UNFCCEB	United Nations Framework Convention on Climate Change Executive Board
WB	World Bank

1.0 Introduction

In this report an assessment of the current Environmental Impact Assessment (EIA) and Strategic Environmental Assessment (SEA) frameworks for use with CO_2 Capture and Storage (CCS) projects is presented. The improvements needed to meet current and future EIA and SEA requirements are identified and the information requirements gaps for conducting EIAs and SEAs for CCS projects assessed.

CCS EIA projects have a number of special characteristics that make them different from normal EIAs and as such may require adaptation of the standard methodologies.

These include:

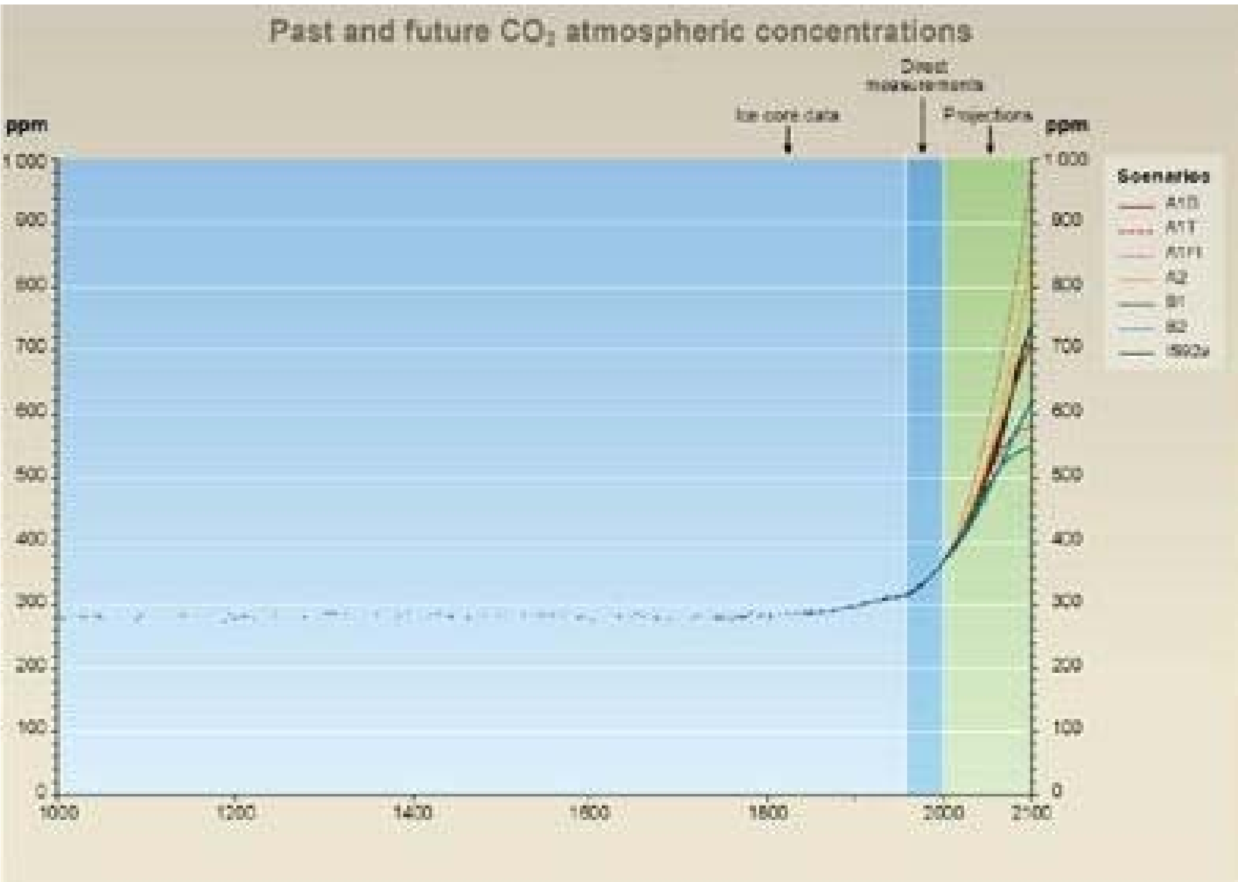
- CCS projects are carried out for the primary purpose of environmental benefit. Assessments will need to consider the potential for early project abandonment to determine at which point the overall environmental benefit becomes positive. There will be an energy cost and therefore a CO_2 cost to doing CCS activities, so projects with a high risk of abandonment before the benefit is derived need to be avoided. This consideration demands a wider scope for the assessment.
- Longer timescale of CCS projects with storage going into hundreds if not thousands of years.
- The potential (global) cumulative effects.
- The international nature of projects. CO_2 could migrate across national boundaries, such that projects sites are truly international. It is conceivable that countries not involved with a CCS project can have emissions within their national boundary from CO_2 that has migrated underground.
- The potential for catastrophic environmental and safety impacts if projects are not planned, implemented and monitored in accordance with good practice.

1.1 Background

Current science indicates that there is a link between climate change and human burning of fossil fuels which release greenhouse gases such as carbon dioxide (CO_2). The gases are believed to trap the heat generated from incoming solar radiation, causing an increase in global temperature. This increasing temperature is understood to result in potentially significant regional changes in climate, such as increased intense storm frequency, drought and sea level rise.

Scientists believe that levels of the greenhouse gases carbon dioxide and methane in the atmosphere are higher now than at any time in the past 650,000 years. Atmospheric concentrations of CO_2 have increased from 280 ppm in the period 1000-1750 AD to 368 ppm in year 2000 (Defra 2004); atmospheric concentrations of methane have increased from 700 ppb for the period 1000-1750 to 1,750 ppb in year 2000. Figure 1.1 illustrates the past and future CO_2 concentrations based on different control actions taken in the 21st century.

Figure 1.1: Past and Projected future CO_2 atmospheric concentrations based on different actions taken in the 21st century



(Source: Intergovernmental Panel on Climate Change 2005)

Carbon (dioxide) Capture and Storage (CCS) is one of the techniques that scientists believe could play a significant role in reducing the accumulation of greenhouse gas emissions in the earth's atmosphere. It refers to the process of capturing CO_2 from large point sources such as power plants and storing it in geological media instead of releasing it into the atmosphere.

DNV Consulting have been commissioned by the International Energy Agency Greenhouse Gas R&D Programme (IEA GHG R&D) to undertake this study, in which the environmental impact assessment methodology that will be required for CCS projects is considered. CCS projects will, by requirement, need to store CO_2 for hundreds to thousands of years and could have environmental, health and safety and liability issues associated with them. The impact assessment methodology for CCS projects is therefore, considered to be an area where adaptation will be required.

1.2 Objectives

The objective in the this study is to review the current Environmental Impact Assessment (EIA) and Strategic Environmental Assessment (SEA) frameworks for use with CO_2 Capture and Storage projects (CCS) for the purposes of:

- determining the degree to which existing frameworks need to be adapted for CCS projects and how these improvements should best be made;
- reviewing future trends and developments in EIA and SEA;
- assessing information requirements and knowledge gaps for conducting EIA of CCS projects, and suggesting research to develop needed techniques to successfully conduct CCS impact assessments.

1.3 Carbon Capture and Storage Projects

The Intergovernmental Panel on Climate Change (IPPC, Benson and Cooke, 2005) defines CO_2 capture and storage (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". CCS is done as an attempt to mitigate the effects of released CO_2 on the atmosphere thus stabilising atmospheric greenhouse gas concentrations.

Put simply, it involves storing emissions of CO_2 securely underground rather than releasing to the atmosphere. Different types of CCS projects are described in more detail in Chapter 2.

1.4 EIA & SEA

In this report Environmental Assessment is an overarching term for both SEA and EIA.

SEA is a systematic process for evaluating the environmental consequences of proposed policy, plans or programme initiatives, in order to ensure the consequences are fully understood and appropriately addressed from the earliest stages of decision making. The SEA approach needs to be developed and tailored to suit conditions, institutional realities and circumstances for individual CCS projects.

Most practitioners view SEA as a decision aiding process rather than a decision making process, and as a tool for forward planning to be applied at various stages of the policy making cycle. Under this broad perspective, SEA encompasses assessment of broad policy initiatives and programmes and plans that have physical and spatial references.

The purpose of the EIA is to clarify the effects that a project's activities may have on the environment, economy, natural resources and society. The impact assessment ensures that these effects are taken into consideration when the activities are planned and when decisions are reached regarding whether, and under what conditions, the activity may be carried out. EIA is site specific.

The concept of environmental assessment via EIA and SEA refers to the examination, analysis and assessment of planned activities with a view to ensuring their environmental, social and economic soundness as a long-term sustainable development. It is a valuable means of promoting the integration of environmental and natural resource issues into planning and programme implementation. Environmental assessment is also a process that brings the proposed action into the public forum and provides an opportunity for study, reporting, comment and feedback on environmental and socio-economic aspects. This public consultation may result in a project being abandoned but, in most cases, results in a better project with improved harmony with interested and affected parties.

Table 1.1 below is a comparison of the differences between EIA and SEA.

Table 1.1: EIA and SEA for CCS Compared

EIA	SEA
Is usually reactive to a proposed CCS development proposal	Is pro-active and informs CCS development proposals
Assesses the effect of a proposed CCS development on the environment	Assesses the effect of CCS policy, plans or programmes on the wider environment or the effect of the environment on the CCS development needs and opportunities
Addresses a specific proposed CCS project	Addresses areas, regions or sectors of CCS development
Has a well defined beginning and end	Is a continuing process aimed at providing information at the right time
Assesses direct impacts and benefits of a proposed CCS project	Assesses cumulative CCS impacts and identifies implications and issues for sustainable development
Focuses on the mitigation of CCS impacts and possible CO_2 leakages	Focuses on maintaining a chosen level of environmental quality
Has a narrow site specific perspective and a high level of detail	Has a wide global perspective and a low level of detail to provide a vision and overall framework. Provides a review of cumulative global effects of CCS
Focuses on specific impacts of a proposed CCS project	Creates a framework against which CCS impacts and benefits can be measured.

Adapted from Strategic Environmental Assessment: A Rapidly Evolving Approach Dalal-Clayton, Barry and Sadler, Barry

With specific relation to CCS, an EIA would be conducted on a particular CCS project, while an SEA would examine CCS opportunities and/or policy on a regional (for example, country-wide) basis.

1.5 Report structure

This report has the following structure:

- *Chapter 2, Carbon Capture and Storage Projects;* an outline of different types of CCS projects.
- *Chapter 3, Review of existing EIA and SEA frameworks;* an assessment of current EIA and SEA frameworks used by selected countries and international organisations. In this chapter a discussion concerning the methodology involved in the review of the frameworks, the key issues that come out of the appraisal, and the strengths and shortcomings of the frameworks identified, is presented..
- *Chapter 4: EIA and Kyoto Mechanisms;* presents consideration of whether CCS projects, if accepted in the future within Kyoto Mechanisms, will require an EIA

under a Kyoto Mechanism regardless of whether host country EIA legislation requires it.

- *Chapter 5, Future trends relating to EIA and SEA for CCS*; an overview of the general expected developments in environmental assessment, plus consideration of items that may need to be incorporated within an EIA specific to CCS.
- *Chapter 6, Information requirements for EIA of CSS projects;* essential on and offshore EIA information is evaluated and a proposed methodology for EIA is produced.
- *Chapter 7, Assessment of environmental issues relating to CO_2 Reservoirs;* as CO_2 injection and storage has some uncertainties, it is considered separately in more detail in this chapter.
- *Chapter 8, Long term issues relating to Carbon Dioxide Storage Reservoirs;* CCS projects will require some form of long-term commitment from plant operators with regards to monitoring of potential CO_2 leakage, ecosystem response, reservoir integrity, decommissioning and eventually abandonment.
- *Chapter 9, Summary of Key Findings*
- *Chapter 10, References*

In support, the following Appendices are attached containing detailed analysis and relevant information:

Appendix A: Legislative spreadsheet
Appendix B: Projects covered by EIA legislation
Appendix C: Projects covered by SEA legislation
Appendix D: Possible structure for risk assessment for a CCS project
Appendix E: CO_2 monitoring

2.0 Carbon Dioxide Capture and Storage

2.1 Introduction

The IPCC Special Report on Carbon Dioxide Capture and Storage (IPPC, Benson & Cooke 2005) defines CO_2 capture and storage (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". CCS is proposed as an attempt to mitigate the effects of released CO_2 on the atmosphere by stabilising atmospheric greenhouse gas concentrations.

Carbon storage is not a new concept. The use of depleted oil and gas formations to store CO_2 extends from the concept of reservoir flooding for Enhanced Oil Recovery (EOR) or the re-injection of CO_2 separated from natural gas (Johnston, 2006). There are a variety of EOR projects being undertaken such as the Weyburn EOR project in Saskatchewan, Canada and the Sleipner offshore gas field development in the Norwegian North Sea. In Norway, Statoil has been injecting 1 Mt of CO_2 per year, for storage since 1996, into a deep aquifer overlying its offshore Sleipner field. Despite these ongoing projects, experience of integrating the different CCS system components, at an industrial scale, is limited albeit that many of the risk, environmental and health and safety issues are now being studied or have been reported in the scientific or interest group literature.

2.2 CCS System Components

CCS involves three stages: capture, transport and storage. The capture of carbon dioxide generated by fossil fuel combustion is done by separating CO_2 from the flue gas either prior to fuel combustion or post combustion. There are a range of capture technologies at different stages of development with some of the technology having been used in the petroleum and gas industry for a significant period of time.

Post-combustion and pre-combustion technologies have both reached an economically feasible state, as seen in Table 2.1. Oxyfuel combustion however, is still at a demonstration phase and more work is needed before it can be used industrially in a CCS process. A 30 MW oxyfuel pilot plant for CO2 capture is being built by Vattenfall near the company's lignite-fired power plant at Schwarze Pumpe, Germany. Construction has started and the plant will be in operation by mid 2008. Several other projects are also underway worldwide. Industrial separation of gases has been done in industry for years and is considered a mature market. All capture technologies however, consume energy and will therefore reduce the efficiency of proposed CCS projects. Carbon capture is, therefore, better suited to large stationary sources and reservoirs with large CO_2 capacity, to minimise the CO_2 development costs in relation to the volumes that will be stored.

CO_2 is captured as a gas and can be transported either by tanker or by pipeline to its injection point. The CO_2 normally needs to be compressed and/or cooled for the transport process. Larger volumes of CO_2 are transported more effectively by pipeline which is an established commercial technology (Table 2.1). Although shipping has reached an economically feasible stage of development, tankers would generally only be functional for smaller volumes (a few million tonnes of CO_2 per year).

Table 2.1 - Current maturity of CCS system components

CCS component	CCS technology	Research phase [13]	Demonstration phase [7]	Economically feasible under specific conditions [5]	Mature market [6]
Capture	Post-combustion			X	
	Pre-combustion			X	
	Oxyfuel combustion		X		
	Industrial separation (natural gas processing, ammonia production)				X
Transportation	Pipeline				X
	Shipping			X	
Geological storage	Enhanced Oil Recovery (EOR)				X[a]
	Gas or oil fields			X	
	Saline formations			X	
	Enhanced Coal Bed Methane recovery (ECBM)		X		
Ocean storage	Direct injection (dissolution type)	X			
	Direct injection (lake type)	X			
Mineral carbonation	Natural silicate minerals	X			
	Waste materials		X		
Industrial uses of CO_2					X

Source: Intergovernmental Panel on Climate Change 2005

In order to prevent the CO_2 entering the atmosphere, it must be stored for long-term periods of hundreds to thousands of years. It can be stored both in onshore terrestrial geological structures and in offshore sub-seabed geological structures. Furthermore, options such as ocean storage and mineral carbonation exist, but these options are in the very early phases of development, and geological storage is currently considered more technically and economically feasible. Ocean storage is considered highly controversial with potentially significant impacts and is generally considered to be non-viable on environmental and safety grounds.

A further aspect that needs to be considered is that unless the CO_2 reacts to become chemically fixed as a mineral whilst in the reservoir, these geological storage structures should be considered as a temporary storage option, even over the long storage periods that are anticipated to be required.

These options are discussed in more depth in the paragraphs to follow.

2.3 Geological Storage

Storage of CO_2 in subsurface geological reservoirs, whether offshore or onshore, is considered more viable and acceptable than ocean storage where CO_2 is stored in the open ocean on the sea floor. There are three main options for storage of CO_2 in geological formations:

- Depleted or near-depleted oil and gas fields (Enhanced Oil Recovery)
- Deep saline aquifers (on or offshore)

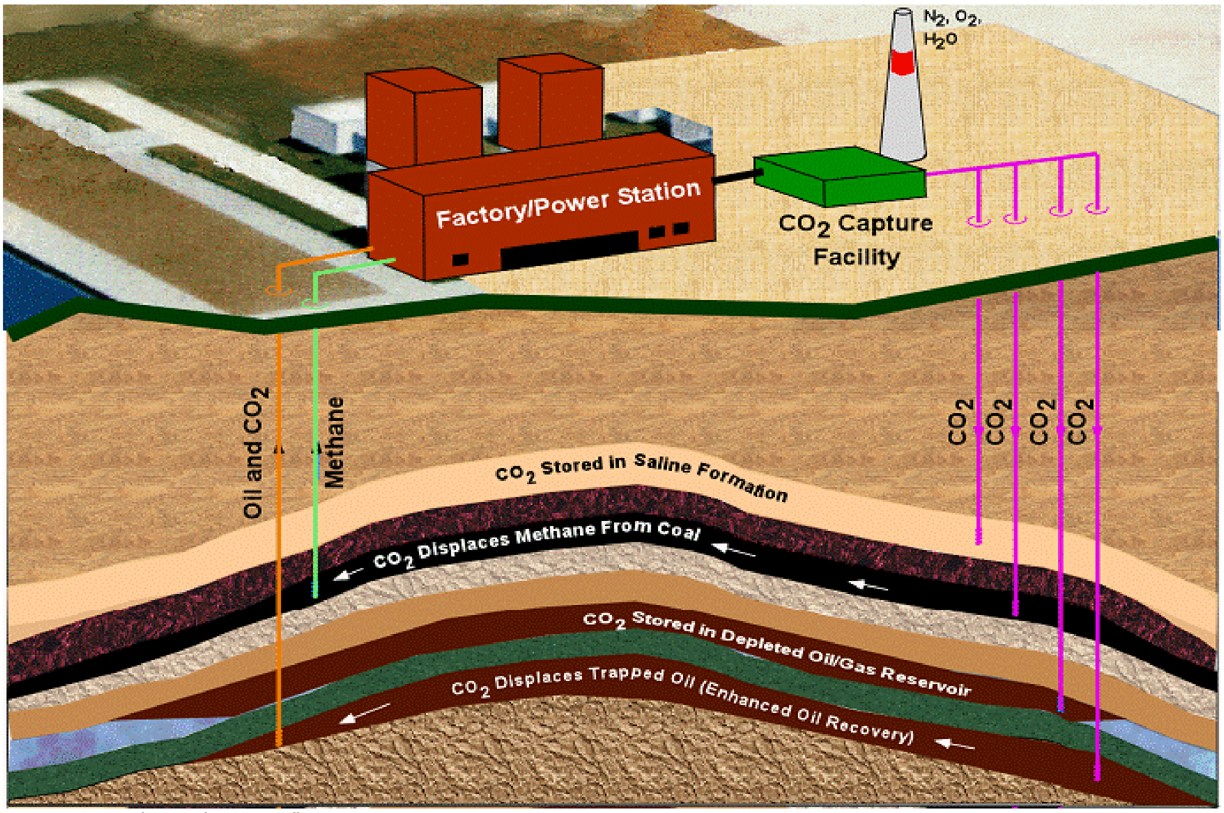
- Unmineable coal seams.

These different options are illustrated in Figure 2.1 and briefly described below.

Enhanced Oil Recovery (EOR) is proposed as a form of CCS. In EOR, CO_2 is used to make hydrocarbons (oil) more available for extraction and in the process some CO_2 is retained in the reservoir. Because EOR ultimately produces more oil which will produce more CO_2 emissions in its various end uses, some consider that the technique does not satisfy the intent of CCS and carbon dioxide abatement. On the other hand, EOR could enable payment for expensive CO_2 capture and transport infrastructure that can later be used for CO_2 storage projects. It is also recognised that EOR could reduce environmental impacts if it avoided new more difficult fields being brought into operation. The total emission cost of EOR, including the additional CO_2 that would be produced as a result of incremental hydrocarbon recovery and combustion would need to be weighed against the CCS and environmental advantage that would be derived.

A relatively new option is the concept of Enhanced Gas Recovery (EGR). In this process, gas is displaced by CO_2, which at elevated pressures has significantly higher density. This gravitational effect can contribute to the effectiveness with which the gas reservoir is swept by CO_2. To date, there are neither demonstration nor commercial applications of this process.

Figure 2.1 – Geological Carbon Dioxide Storage



Note: Cap rock not shown on figure

Deep saline aquifers (permeable rock layers containing salty water deep underground) have been identified as an option for CCS. CO_2 can be stored in permeable rock under a cap rock at depths greater than 800m below surface where it is kept in a supercritical state (state where the CO_2 takes on fluid like properties). In this state and at this depth the CO_2 is buoyant under most conditions and will move upwards through the permeable rock layer. If the geological layers above the permeable rock offer an effective seal, the CO_2 is trapped and stored. Permeable rocks commonly have their pore spaces filled with water in which injected CO_2 may dissolve and the resulting slight density increase in the CO_2 - water mix, suggests it will sink. The CO_2 may also react chemically with water or minerals in the rock to form carbonates and become permanently locked in the geological formation.

The coal bed storage option would take place at shallower depths and relies on the absorption of CO_2 on the coal, but the technical feasibility largely depends on the permeability of the coal bed, and this method is unlikely to account for more than a few percent of CCS projects (see Table 2.2).

2.4 Ocean Storage

There are two ways in which carbon can be stored in the ocean although it should be noted that many stakeholders clearly oppose ocean storage due to potential impacts upon the sea floor, where a very important link in the chain of the oceans ecosystem resides. The first method is by injecting and dissolving CO_2 into the water column (typically below 1,000 meters) via a fixed pipeline or a moving ship. The second option is to deposit CO_2 via a fixed pipeline or an offshore platform onto the sea floor at depths below 3,000 m, where CO_2 is denser than water and is expected to form a "lake". It is hoped that the dissolved and dispersed CO_2 would become part of the global carbon cycle and eventually equilibrate with CO_2 in the atmosphere. Ocean storage is, however, still in the research stage and the ecological impacts (most notably increased acidity) are currently being studied.

As seen in Table 2.2, ocean and saline aquifers present the largest opportunities for storage of anthropogenically derived CO_2.

Table 2.2: Estimates of Carbon Reservoirs (Johnston, 2002)

Table 1 estimates of carbon reservoirs of different biosphere compartments and order of magnitude estimates of potential capacities for carbon sequestration (adapted from Herzog 2001)

Reservoir size	**Gt (billion tonnes) carbon**
Oceans	44 000
Atmosphere	750
Terrestrial	2 200
Sequestration potential	**Gt (billion tonnes) carbon**
Oceans	1000s
Deep saline formations	100s-1000s
Depleted oil and gas reservoirs	100s
Coal seams	10s-100s
Terrestrial	10s

Source: Intergovernmental Panel on Climate Change

2.5 Mineral Carbonation

Mineral carbonation is another option for consideration. Carbonation is the process of reacting naturally occurring minerals to form carbonates. The reaction is extremely slow in nature (in the order of a hundred thousand years), and the challenge is to speed up the reaction in order to design an economically viable process.

The simplest process would be direct carbonation – reacting the rock directly with the CO_2, but the kinetics of this approach are much too slow; as a result many different reactions have been explored. While progress is being made, none are currently near resolving all the issues necessary to make a commercial process.

Mineral Sequestration has three advantages:

- carbonates have a lower energy state than CO_2 and thus, theoretically, the process requires no energy inputs and could potentially produce energy
- the raw materials are abundant
- this is the only form of carbon storage that is permanent. The other major proposed storage options -- terrestrial, geologic, and ocean – have the potential for leakage over time, which presents liability, environmental, health and safety issues.

For mineral carbonation, the challenge is to improve carbonation reaction kinetics in order to develop an economically acceptable commercial process.

3.0 Review of Existing EIA & SEA Frameworks

3.1 Objectives of Framework Review

The main objectives in this framework review are to determine:

- Common best practice EIA & SEA processes
- The degree to which existing frameworks need to be adapted for CCS projects to meet EIA & SEA best practice requirements
- How the changes for CCS EIA & SEA are best made
- Shortcomings or omissions in current frameworks if used for CCS projects.

A comparative review approach has been used in order to ensure identification of best international practice and to create the opportunity for the development of EIA & SEA methodology that would be internationally applicable to CCS projects. This would allow the EIA to become the vehicle for presentation of proposed projects to local governments for authorisation as well as a vehicle for presenting proposed projects to the UN Framework Convention on Climate Change Executive Board (UNFCCC EB) for approval as part of a carbon credit scheme.

It should be noted that this report is not intended to be a legal interpretation of EIA & SEA legislation, and that:

- regulations within some countries may be interpreted and applied differently than as set out in the frameworks, and this study does not capture such detail.
- Some countries may have legal requirements, other than through EIA and SEA regulations, that require some form of environmental assessment.

3.2 Frameworks Reviewed

In order to be as inclusive and comprehensive as possible, the EIA and SEA frameworks in the table below have been included as part of the methodological review conducted in this study. Only a selection of European countries have been reviewed, as they generally follow EU guidelines.

Table 3.1: International and European EIA and SEA Frameworks

International Guidelines/Frameworks	DOES IT COVER EIA OR SEA	Originator
Operational Policy 4.01.	EIA	International Finance Corporation (IFC). Environment Division
Principles of EIA Best Practice.	EIA	International Association of Impact Assessment (IAIA).
Convention on EIA in a Transboundary Context 1991.	EIA	UNECE.
Protocol on SEA to the Convention on EIA in a Transboundary Context.	SEA	UNECE
European Union Frameworks		
Council Directive 97/11/EC of 3 March 1997 amending Directive 85/337/EEC on the assessment of the effects of certain public and private projects on the environment	EIA	European Commission
Directive 2001/42/EC of the European Parliament and of the Council of 27 June 2001 on the assessment of the effects of certain plans and programmes on the environment	SEA	European Commission
Core Countries		
Environmental Impact Assessment Act 2001.	EIA and SEA.	Germany.
Environmental Management Assessment Regulations 2005.	EIA	Netherlands.
Town and Country Planning (EIA) (England & Wales) Regulations 1999.	EIA	UK
The Environmental Assessment of Plans and Programmes Regulations 2004.	SEA	UK
Environment Protection and Biodiversity Conservation Act 1999 (EPBC Act)	EIA & SEA.	Australia
Canadian Environmental Assessment Act, 1992, amended 2003.	EIA	Canada
Directive on Environmental Assessment of Policy, Plan and Programme Proposals.	SEA	Canada
Environmental Impact Assessment law**,** Law No. 81 of 1997	EIA	Japan
Regulations relating to Environmental Impact Assessment, 2005	EIA	Norway
The National Environmental Policy Act of 1969	EIA & SEA.	USA
DNV Framework		
DNV EIA Framework (derivative framework of the above)		DNV

3.3 Methodology for review of frameworks

The first objective of this study was to determine the degree to which existing frameworks need to be adapted for CCS projects to meet current EIA & SEA requirements, and how these improvements should best be made.

The first stage of this review involved mapping the different frameworks detailed in Table 3.1 against key stages in the DNV EIA process methodology. The DNV EIA methodology is based on International Finance Corporation (IFC) guidelines combined with best practice identified from countries where DNV operates. Table 3.2 provides an overview of the EIA stages.

Table 3.2 DNV EIA Methodology

Stage	Description
Screening	Screening involves the determination of whether or not an individual proposal requires further assessment and to what level of detail. Proposal screening often uses screening criteria contained within National EIA legislation and/or loan organisation practices. Discussion with the authorities and key affected parties will be required.
Scoping	Scoping of the EIA study and development of the Terms of Reference (TOR). This allows the study to establish the key issues and impacts to be addressed and the framework or boundary of the study. This stage should ideally involve some public consultation.
Analysis of Alternative Options	To establish the preferred or most environmentally sound or benign option for achieving proposal objectives, an analysis of alternative options must be carried out, as well as a balanced description of why they are considered inferior to the proposed description.
Project Description	Description of the project including size, location, timetable, and nature of the proposed development.
Environmental Baseline Review	Collection of environmental baseline data from the open literature and field measurement. This will include discussions with local authorities, Interested and affected parties and other stakeholders.
Legislative Review	A comprehensive review of local, regional, national and international environmental legislation that could affect the proposed development.
Impact Identification	Identification of those aspects of the project that could impact upon the environment, society or economics. Impacts will include positive and negative, direct and indirect effects as well as secondary, cumulative, short/ medium/ long-term, permanent and temporary effects. Impacts should be openly reported to all Interested and Affected parties, Authorities and Stakeholders.
Impact Prediction	Qualitative, semi-quantitative or quantitative prediction of the significant environmental, social and economic impacts associated with the project. Environmental risk assessment and modelling may be used to assess uncertain impacts.
Impact Significance	Prioritisation and screening exercise leaving only those impacts considered significant or highly uncertain for further consideration.
Impact Mitigation	Development of hardware and management controls that can be used to mitigate significant or uncertain impacts. Mitigation measures may require redesign of unacceptable aspects associated with the project.
Environmental Management Plan	Development of impact mitigation measures into an environmental management plan. Provides a demonstration that institutional management systems are able to assimilate project specific requirements.
Environmental Monitoring programme	Development of an environmental monitoring programme to verify that impact predictions are consistent with real world experience. Monitoring is particularly important where impact predictions are uncertain.
Reporting	Reporting of the EIA process, including the development of a non-technical summary or statement (EIS) which clearly and impartially documents the impacts of the project, the proposed mitigation measures and the significance of the effects. The EIA must be suitable for describing the project to the general public, stakeholders and decision makers.
Review	Review of EIA as part of the application process to determine if the report is a satisfactory assessment of the project, and contains the information required for decision making. This may involve discussions with decision makers, stakeholders and general public. The project may be accepted (perhaps subject to conditions) or rejected (either outright or subject to redesign).
Project Implementation and Operation	Regular environmental monitoring reviews should take place. Significant deviations from expectation may require retrofitting or modification of the development as well as further consultation with the Authorities and Interested and Affected parties. This phase would be managed possibly using external or 3rd party verification.

The aim of the review was to highlight the existing gaps in the frameworks in relation to each stage of the environmental assessment process. A detailed analysis is presented in Appendix A. The analysis is presented as a spreadsheet detailing the EIA process for each country or international body relative to the DNV methodology.

In reviewing the SEA frameworks, the frameworks were mapped using a methodology that broadly reflects the EIA methodology with a number of modifications or elaborations to account for the strategic nature of SEA. This is also presented in Appendix A.

The *first stage* of the review was competed by identifying:

- Elements that would add value to international EIA and SEA methodologies for CCS and could be considered as "good practice". A best practice environmental assessment framework was developed and is shown schematically below in Figure 3.1 for EIA (it is derived from the highlighted green sections of the spreadsheet in Appendix A), and discussed further in section 6.4.

- Identification of key general EIA & SEA issues where there appear to be gaps in the legislative framework (these are highlighted in yellow on the spreadsheets, are summarised towards the bottom of the spreadsheet and discussed in sections 3.4 and 3.5 below).

The *second stage* of the review focussed more specifically on CCS projects, and considered questions such as:

- Would CCS projects be captured by the existing EIA and SEA legislation?
- Do the frameworks cover stewardship of projects?
- What project lifetime is covered by the frameworks?
- Do the frameworks require provision for decommissioning?
- Is the EIA/SEA required to include cumulative effects?
- Do the frameworks require the use of guidance documents produced by various departments or bodies?

The outcome of both stages is presented in section 3.4 and 3.5 below (and incorporated within the spreadsheets in Appendix A for both EIA and SEA).

3.4 Overview of Existing EIA Frameworks

The information in the Table 3.3 below provides an overview of the issues identified in the review:

Figure 3.1: Best Practice Environmental Assessment Framework

Stage	Description
Screening	Screen to determine whether or not the project requires an EIA. Consultation with interested parties, governments or authorities as required.
Scoping	The aim of the scoping process is to determine the items and issues to be addressed in the EIA (terms of reference). The developers should outline the methods to be used in the course of the EIA. Interested and affected parties should be given the opportunity to comment on the scope of the EIA.
Analysis of Alternative Options	Developers should include a description of the alternatives to the proposed project. The description should include an assessment of the potential impacts and potential mitigation. The option of not progressing the proposed activities should be considered.
Project Description	The developer should include a comprehensive description of the project in the EIA. The description should cover the lifecycle of the project (i.e. construction, operation, maintenance, decommissioning). It should include an overview of: size, location, timetable of the project, proposed land use, nature and quantity of construction materials, description by type and quantity of the expected residues and emissions (noise; water; air; soil pollution; vibration; light; heat etc).
Env. Baseline Review	The objective of the baseline review is to describe the state of the environment as it is prior to commencement of project operations. The review should describe the flora & fauna; water (aquifers; water courses; shore lines; existing discharges); soil (geology; geomorphology; including seismic characteristics); air (quality; climatic factors); architectural, historic and cultural heritage.
Legislative Review	Developers should include in the documentation an outline of the policy, legal and administrative framework within which the EIA is prepared It should include all relevant legislation at a local, state/ territory, regional, national and international level that could affect the proposal. Also, development of a CCS site should not conflict with other legislation.
Impact Prediction	The impacts identified in the preceding stage should be quantified via qualitative, quantitative and semi-quantitative techniques. Developers should consider frequency, duration, magnitude, risk etc.
Impact Significance	In determining the significance of activities, developers should consider the size of the project; location (near SSSI's); and the nature of the effects. Impacts should be screened and prioritised accordingly.
Impact Mitigation	Developers should provide a description of the measures which will be taken to avoid; reduce; or remedy significant adverse effects. The description should include an overview of the predicted or expected cost effectiveness of the measures; the statutory or policy basis of the measures; cost of mitigation.
Env. Management Plan	The environmental management plan should contain a framework for the continuing management and mitigation of the project including consideration of who will be responsible.
Env. Monitoring	The environmental monitoring programme should provide a detailed programme for monitoring which is appropriate to the nature, location and size of the storage reservoir. Developers should consider the nature of monitoring techniques to be used (there may possibly be minimum standards for pipelines).
Reporting	The developers should prepare a draft EIA report containing a non-technical summary of the aforementioned information
Review	The draft report should be submitted to the relevant authorities/ bodies for review. It should also be made available for review and comment by interested and affected parties and the general public. The comments should be fed back to the developers which should finalise the report in light of the comments received. The responsible authority should review the final documentation and make a decision in light of the report and consultation. Conditions may be attached to the approval e.g. relating to mitigation measures to be taken.
Project Implementation and Operations	Developers should engage in monitoring and environmental management as per the plan. The aim of monitoring is to assess the effectiveness of the mitigation measures and to identify unforeseen effects. The responsible authority should ensure that any conditions attached to the approval are being met and that any required monitoring and reporting is reviewed.

Table 3.3: Overview of Existing Frameworks for EIA

Country	Key Issues	CCS specific issues.
Australia	The Australian system is complicated by the fact that although the Environmental Biodiversity and Conservation (EBCA) Act is intended as an overarching methodology, a number of states/ territories regulate their own EIA process in addition to the Federal government. Under the existing regime, theoretically two EIA's may need to be carried out in those states that operate their own system in addition to the EBCA system. To get around this, under the ECBA, bilateral agreements can be set up which enable the EIA process in the relevant state/ territory to be accredited or approved at the Federal level thereby removing the need for 2 EIA's. The Australian regime is one of the few that requires developers to explain the context of the project with reference to the planning framework (essentially a legislative review).	Carbon storage projects are not specifically mentioned in the Act, however according to the review conducted by ERM into permitting issues for such projects, CCS may be covered if the definition of petroleum were to be altered to include carbon dioxide. Western Australia is slightly more advanced in relation to CCS projects and recently enacted the Barrow Island Act governing carbon dioxide storage under Barrow Island.
Canada	The main issue in relation to the Canadian framework relates to the apparent absence of a requirement to conduct a baseline review. This was queried with the Canadian Environmental Assessment Agency, the Director of which explained that the Act itself sets out the basic responsibilities and requirements but not details of the assessments required; therefore the Act itself does not specifically require a baseline review. However in order to assess potential environmental effects it is understood that there needs to be a reasonable understanding of the existing environment, particularly the valued ecosystem components. Another apparent gap in the legislation relates to the absence of a requirement to conduct a legislative review.	CCS projects are not specifically mentioned in the Act, however according to the review (ERM 2006) into permitting issues, CCS may be covered if the definition of petroleum were to be altered to include carbon dioxide. However there is in existence a CCS Technology Network which is designed to promote the development of CCS projects. Canada has a robust system for the licensing and permitting of sour gas pipelines, ERM conclude that the regime could be easily conferred onto the transportation of CO_2. There is precedent in Canada of regulation of the transportation of CO_2. Saskatchewan explicitly includes the transportation of CO_2 in the definition of a pipeline under the Pipelines Act.
European Community The European Directive does not govern EIA in Europe per se, it establishes the broad process to be taken by member states in transposing into national legislation	Under the Directive, Scoping is not an element that member states have to provide for in national legislation. However it asks Member States to consider establishing a mechanism to enable developers to seek scoping advice in relation to the development of terms of reference for the EIA. Gaps in the legislation relate to: apparent lack of a requirement to conduct a legislative review; No explicit reference to the development of an environmental management plan -although they do require developers to describe the measures to be taken to mitigate the adverse effects of the project; post implementation monitoring is not required although it is considered good practice.	Carbon storage projects are not specifically mentioned in the Act; however, CCS may be covered if the definition of petroleum/ oil or gas were to be altered to include carbon dioxide.
France	The French environmental code contains limited detail, with more detailed requirements relating to consultation contained in other legislation. The system appears to rely more on guidance documents than detailed direction.	Carbon storage projects are not specifically mentioned in the legislation.

Country	Key Issues	CCS specific issues.
	Gaps in the legislation relate to: apparent lack of the requirement to conduct a legislative review; no explicit requirements to assess the significance of impacts; no explicit reference to environmental management plan or environmental monitoring programme; no reference to post implementation monitoring.	
Germany	The requirements for an EIA and SEA have been incorporated into the same Act. As Germany is a member of the EC, it is obliged to translate the pertinent EC Directives into national legislation and as such broadly reflects the gaps associated with the European EIA Directive. In relation to scoping, which is not required to be translated into national legislation, Germany does provide for access to scoping advice. In relation to impact assessment, developers are not required to consider "cumulative effects" of the project.	Carbon storage projects are not specifically mentioned in the Act. .
Japan	It was only possible to access English translations of the 1997 Act, and as such it was difficult to determine if the legislation had been updated, superseded or amended. Gaps in the framework relate to: - apparent lack of requirement to conduct a legislative review; - Analysis of alternative options is not explicitly mentioned in the Act; - Whilst developers are required to describe proposed mitigation measures there is no explicit requirement to incorporate them into an environmental management plan; - The requirement to develop an environmental monitoring programme is not mentioned in the Act, however follow up environmental conservation surveys are considered best practice; - Developers do not appear to be specifically required to consider "cumulative effects" of the project.	Carbon storage projects are not specifically mentioned in the Act.
Netherlands	As the Netherlands is a member of the EC, it is obliged to translate the pertinent EC Directives into national legislation. The only gap in the Dutch legislation relates to the lack of a requirement to conduct a legislative review.	Carbon storage projects are not specifically mentioned in the Act,
Norway	Gaps in the framework relate to: Apparent lack of the requirement to conduct a legislative review. Consideration of cumulative effects is only mentioned in relation to the requirement to consider the cumulative effect to nearby projects.	Carbon storage projects are not specifically mentioned.
IAIA	The document issued by the IAIA is not a legislative framework, but best practice guidance relating to what should be included in each stage of an EIA. No best practice guidance was included in the document for: Legislative review. Baseline review. Project description.	Carbon storage projects are not specifically mentioned.
IFC	The IFC framework is not legislative in nature, it is an operational policy and is applied when project developers apply for investment from the IFC. Upon receipt of an application for investment, the IFC	Carbon storage projects are not specifically mentioned.

Country	Key Issues	CCS specific issues.
	assigns environmental specialists from the Environment department to provide guidance to the developers on environmental and social requirements to be considered in the documentation submitted in support of an application for investment. The only gap in the policy relates to the absence of a requirement to consider "cumulative effects" of expected adverse impacts.	
UK	As the UK is a member of the EC, it is obliged to translate the pertinent EC Directives into national legislation and as such broadly reflects the gaps associated with the European EIA Directive. In relation to scoping (not required to be translated into national legislation) the UK does provide for access to scoping advice.	Carbon storage projects are not specifically mentioned in the Act, however according to the review conducted by ERM into permitting issues for such projects, CCS may be covered if the definition of petroleum were to be altered to include carbon dioxide.
UNECE	The UNECE Framework relates to EIA in a transboundary context. Gaps in the framework relate to: Stage one in the convention relates to notification of to neighbouring countries of an activity that may have transboundary effects. Lack of requirement to conduct a legislative review. No mention of requirement to consider "cumulative effects" of adverse impacts.	Carbon storage projects are not specifically mentioned.
USA	The National Environmental Policy Act (NEPA) as amended incorporates the requirements for both EIA and SEA, and there are numerous guidance documents associated with the Act. Gaps relate to: No requirement to put together an environmental management plan, although a similar intent is included in the Code of Federal Regulations number 40 on Environmental Protection. No requirement to put together an environmental monitoring programme although a similar intent is included in section 6.105 of the Code of Federal Regulations number 40 on Environmental Protection.	Carbon storage projects are not specifically mentioned in the Act, however according to the review conducted by ERM into permitting issues for such projects, CCS may be covered if the definition of petroleum were to be altered to include carbon dioxide.

3.5 Overview of Existing Frameworks for SEA

Table 3.4: Overview of Existing Frameworks for SEA

Country	Key Issues	CCS specific issues.
Australia	The only gap relates to the lack of requirement to monitor the environment after the implementation of the plan or programme.	Carbon storage projects are not specifically mentioned in the Act. However Western Australia is slightly more advanced in its thinking than the Federal Government in relation to CCS projects and recently enacted the Barrow Island Act governing carbon storage under Barrow Island.
Canada	There are no apparent gaps in the SEA framework.	Carbon storage projects are not specifically mentioned in the Act, CCS may be covered if the definition of petroleum were to be altered to include carbon dioxide.
European Community	There are no apparent gaps in the SEA framework.	Carbon storage projects are not specifically mentioned in the Act, CCS may be covered if the definition of petroleum were to be altered to include carbon dioxide.
France	There do not appear to be any gaps in the SEA framework.	Carbon storage projects are not specifically mentioned in the pertinent legislation.
Germany	A gap relates to the lack of requirement to monitor the environment after the implementation of the plan or programme.	Carbon storage projects are not specifically mentioned in the Act, CCS may be covered if the definition of petroleum were to be altered to include carbon dioxide.
Japan	At present Japan does not have a methodology for SEA, although the Ministry of the Environment is currently considering implementation of SEA requirements.	Not applicable because Japan does not currently have a framework covering SEA.
Netherlands	At present the European SEA Directive has not been translated into national Dutch legislation. They currently apply the SEA directive as it stands and, where appropriate, they apply their own quality checks. However they have what they call the "E-test", which relates to the environmental assessment of new legislation. It is designed to check whether the legislation has unintended effects, e.g. undermining the objectives of government policy. Draft legislation has to be assessed against a series of questions designed to identify whether it has any unintended consequences.	
Norway	As far as could be determined there are no guidelines for SEA in Norway. Within the Oil industry, regional EIA's are performed both by the operators themselves (every 5 years) and by the Government before new acreage is opened for licensing (this appears to be as close as Norway comes to SEA). No specific methodology exists but there are many methods and models used for specific tasks of the impact assessment work.	Not applicable because Norway currently does not have a framework covering SEA.
IAIA	To date the IAIA has not issued best practice guidance relating to SEA however they have issued SEA performance criteria designed to provide guidance on what a quality SEA process should be, e.g. integrated, sustainable, participative, iterative.	Not applicable because the IAIA has not as yet issued best practice guidance relating to SEA.
IFC	Contact with the IFC and World Bank revealed that "SEA is non-mandatory for, assessing requests for financial assistance, unlike EIA under operational policy 4.01. However they stated that SEA could be applied to satisfy the environmental assessment requirements of a particular strategy, policy, plan or programme that is likely to have significant sectoral or regional environmental impact. Environmental assessment is mandatory in these cases under operational policy 4.01. SEA could be used under operational policy 8.60 on development policy lending. The policy requires the Bank to determine whether specific country policies supported by policy lending operation are likely to have significant effects on the country's environments. For policies with significant effects, an assessment is required	Not applicable because the IFC has not issued a specific operational policy governing application of SEA considerations to requests for financial development assistance

Country	Key Issues	CCS specific issues.
	by bank staff of the country's systems for reducing adverse effects and enhancing positive effects, drawing on relevant country level or sectoral environmental analysis. As a sectoral environmental analysis is a type of SEA, this policy suggests that the Bank could draw information as needed from existing SEA's. In addition, the assessment of the significance of effects and country capacity to manage them, needs to be carried out under this policy and could be satisfied by applying SEA".	
UK	There are no apparent gaps in the SEA framework.	Carbon storage projects are not specifically mentioned in the Act, CCS may be covered if the definition of petroleum were to be altered to include carbon dioxide.
UNECE	There are no apparent gaps in the SEA framework.	Carbon storage projects are not specifically mentioned.
USA	The SEA process is incorporated into the NEPA Act under the Federal plans. The information is somewhat limited and people responsible for federal plans refer to guidance documents for assistance.	Carbon storage projects are not specifically mentioned in the Act, CCS may be covered if the definition of petroleum were to be altered to include carbon dioxide.

3.6 Discussion

It was found that the main stages of EIA and SEA from countries around the world are similar, but by no means the same. In many cases, some elements of good practice EIA are not actually required by law. This does not necessarily mean these elements do not take place, either as part of good practice, or as demanded by the regulator, just that they are not legally required. It can therefore be considered that there are general gaps in the EIA frameworks, although there may be no specific need to alter the country specific EIA/SEA regulatory frameworks in regard of such general differences, unless national feedback indicates that EIA and SEA has not been working in practice. With regard to compliance with CCS best practice however, EIA frameworks may well require amendment to ensure that they meet the minimum requirements needed for acceptance by mechanisms such as CDM and JI Clean Development Mechanism and Joint Implementation).

It is proposed that there are two main areas which need to be considered in more detail to ensure the requirements specific to CCS projects are addressed:

- Is there a specific requirement in existing EIA and SEA frameworks for CCS project to have an impact assessment? And does legislation require the use of available international guidelines? This is considered below.

- Is the stewardship of a CCS site, over the long term (10,000 years), required and considered by the existing frameworks? This issue is discussed separately in the Chapter 8.

3.6.1 Requirement for Environmental Assessment for CCS

In Appendices B and C, reviews are presented of the current environmental legislative frameworks for EIA and SEA that consider the types of projects currently captured by EIA and SEA legislation. A summary is presented below.

EIA

Appendix B considers the types of projects currently captured by EIA legislation in the countries within the scope of the study. CCS projects are not currently specifically mentioned because the technique is relatively new. However, CCS projects may be captured under other areas identified in the EIA legislation, as highlighted below.

It is found that in some cases CCS projects may be captured by current legislation. For example, in the EU, a new proposed development involving CCS from a power station may be captured by existing EIA legislation because the Directive requires "…any change or extension of projects listed in Annex I or Annex II, already authorised, executed or in the process of being executed, which may have significant adverse effects on the environment". Because the new proposed development would require significant extension to the power station, the CCS development would be captured by the framework, and require consideration through an EIA.

However, this may not be the case for all proposed CCS developments, as there are many different types of CCS that may not require change or extension of Projects listed in Annex I or II.

Similarly, there is an argument that if the definition of oil or gas is amended then CCS projects would be captured by EIA legislation in many cases.

It is suggested that the simplest mechanism to ensure capture of a CCS development may be to amend EIA legislation in national countries such that CCS projects are specifically required to be subject to an EIA (this is only recommended for those countries where specific activities are detailed in the legislation). Additionally, although legislation often refers to guidelines for conducting EIAs, in many cases it does not specifically require the use of the guidelines. So in amending legislation with respect to CCS projects, it is suggested that the use of available international guidelines is tied in for CCS projects.

SEA

Appendix C considers the types of projects currently captured by SEA legislation in the countries within the scope of the study. CCS projects are not currently specifically mentioned because the CCS technique is relatively new. However, CCS projects may be captured under other areas identified in SEA legislation, as highlighted below.

It is found that in some cases CCS projects may be captured by current legislation. For example, in the EU (and the Netherlands which currently applies the directive as it stands), a new proposed development involving CCS from a power station may be captured by the existing SEA framework because the Directive requires plans or programs which are prepared for industry and which set the framework for future development consent of projects under the EIA directive to be subject to an environmental assessment. Therefore, theoretically, if the EU decided that a programme of CCS projects was going to be instituted, an environmental assessment would be carried out of the likely storage areas/regions (e.g. North Sea) in order to identify in advance the areas where applications for development consent for individual storage projects would or would not be considered. In relation to the UK and UNECE Convention, the same conclusion applies because the text of the British legislation and UNECE Convention broadly reflects that of the EU directive.

In relation to the USA it is possible that CCS projects would be covered under section 1502.4, which requires agencies when considering statements on broad actions to evaluate proposals in a number of ways including geographically. Whilst the wording of the text is very broad, theoretically if an agency was considering CCS they would be required to consider the proposal in relation to the locations being considered hence some consideration of geology etc would be required before the proposal was approved.

In relation to Australia, Canada and Germany, the situation is less clear because the legislation is quite broad and no conclusions have been drawn. With respect to Norway, Japan, the IAIA and IFC, no conclusions are drawn because they do not appear to have the relevant legislation in place at this time.

4.0 EIA and Kyoto Mechanisms

In this section, discussion is presented on whether CCS projects, if accepted in the future within Kyoto Mechanisms, will require an EIA under a Kyoto Mechanism and if the EIA evaluated by relevant National Authorities will be acceptable under Kyoto. The current situation is that currently no country has yet included the CCS option in their existing EIA framework. If a Kyoto mechanism such as CDM requires an EIA to a particular standard, for example, it may be possible for host countries to adopt that standard as opposed to having to amend their national EIA legislation to ensure CCS projects are captured within in an EIA process. One particular issue relates to the capacity of the host countries to specify requirements for and provide guidance and review of CCS EIAs and the capacity of the CDM EB to evaluate the EIAs that have been approved by the host countries.

4.1 Kyoto Protocol

There are three mechanisms included in the Kyoto Protocol:

- **Clean development mechanism (CDM**) - The CDM scheme is an incentive for companies in industrialised countries (Annex 1) to invest in eligible emissions reduction projects in developing countries (Non Annex 1). It assists Parties not included in Annex I in achieving sustainable development and in contributing to the ultimate objective of the Convention, and assists Parties included in Annex I in achieving compliance with their quantified emission limitation and reduction commitments (Article 12 of the Kyoto Protocol).
- **Joint Implementation (JI)** – the JI scheme is an incentive for companies in industrialised countries to reduce emissions through cooperative efforts (Article 6 of the Kyoto Protocol). JI rewards emissions reduction initiatives, and countries can use the emission reduction credits earned to meet reduction commitments. A JI project might involve (e.g.) replacing a coal fired power station with a more efficient CHP plant; in practice, JI projects are most likely to take place in Economy in Transition (EIT) countries.
- **International Emission Trading (IET)** - Through IET industrialised countries are allowed to meet their commitments by buying and selling excess emissions credits among themselves (Article 17 of the Kyoto Protocol). There are no “projects” involved.

Both the CDM and JI schemes relate to the project level where EIA to a set standard could be used. IET relates to trading at the international level so there is little likelihood of EIA becoming a decision tool in it.

4.2 EIA & Kyoto Protocol

It is not anticipated that a CCS project would be accepted under the CDM/ JI schemes without an EIA. Work is currently underway by DNV to take the EIA methodology presented in this document and integrate it into the CCS CDM methodology along with a Storage Performance Assessment (SPA) which is a characterisation, monitoring and remediation programme linked to the EIA and the CDM CERs. This integrated approach is planned for potential presentation to the UNFCCC for their consideration. Although other types of projects do not need EIA's under the CDM/JI scheme, if they are not required by host country law, it is not expected this would be seen as appropriate by Designated Operating Entities (DOEs), stakeholders and the Executive Board (EB) of the UNFCCC accreditation system for CCS projects. This is due to CCS projects potential environmental and health and safety impacts and the associated liability, if any of these impacts were to be realised. DOEs are accredited by the UNFCCC to validate and subsequently request registration of a proposed CDM project activity (and are therefore likely to be the first CDM EIA review point outside of the host country).

For other types of projects, documentation on the analysis of environmental impacts, including transboundary impacts, is required for the validation of the Project Design Document (PDD) only if the EIA is required by law and/or if an EIA has been carried out. The PDD, together with other documentation, is the basis for project registration and its recognition as a credible CDM project. For other types of projects, a list of environmental impacts where no EIA has been carried out might suffice.

It is therefore proposed, as a result of the nature of CCS projects, that CCS under the CDM be required to submit an EIA to this specification and any other additional guidelines as may be required in the future. This means a host country and the CDM CCS EIA process may require duplicated effort and the host country could resent that a standard external to the country is being required as part of the approval process. Issues around this need to be resolved between the UNFCCC and Non-Annex 1 Countries. It is possible that an UNFCCC expert panel to help the host countries develop the capacity to this EIA process may be a way forward as well as introducing an improved standard in EIA. It will also enable authorisations and permits to be granted without delays.

This possible way forward is required as there are a number of barriers to developers getting a CCS project without an EIA approved under the CDM /JI schemes. These are:

- The DOE will likely seek an EIA as part of working to best practice. If best practice is not defined, it is likely that the validation of PDDs for CCS projects will be put on hold until this is resolved. Many projects are currently on hold for far less important issues – of the ~800 projects proposed for CDM approval only ~120 have been approved. It is unlikely that any DOE will validate the PDD for any CSS projects until such a methodology is approved and capacity has been built to evaluate these proposed projects and EIAs. DOE minimum standards for validating a PDD of a CCS project are expected to be incorporated into the Validation and Verification Manual, to which the DOEs comply on a voluntary basis.
- The requirement for DOEs to respond to the comments of Stakeholders, such as environmental NGOs. If a PDD was not accompanied by an EIA, it might not be possible for the DOE to assess if stakeholder comment has been addressed without an EIA being carried out.
- The Executive Board (EB) would be expected to request a review of any CCS project without an EIA. A CCS project without an EIA would only get to the EB for approval if the DOE ignored the lack of EIA and stakeholders failed to comment on the lack of EIA. The EB could theoretically remove the accreditation of a DOE in response to the failure to insist on an EIA for a CCS project.

The Kyoto Mechanisms are currently guaranteed up to 2012. Although these are likely to continue in some form beyond 2012 and additional countries might be included, how support will be organised post-2012 has not yet been agreed and, looking forward, uncertainty therefore remains. This is of particular importance to CCS projects as they are expected to operate for considerable lengths of time and require storage to be verifiable for several hundred years at least.

It is also important to note that CDM/JI projects must be developed within national boundaries. Projects developed in international waters are outside national boundaries as are those which cross national boundaries. Therefore, through the EIA, it is important to ensure that lateral migration of the stored CO_2 does not cross National boundaries. There is a clear distinction here between the impact boundary (at least lateral migration boundary) and the project boundary.

It is also important to consider that some countries have chosen not to sign or ratify the Kyoto Protocol. Projects in countries that have not ratified the Kyoto Protocol, such as Australia and the USA, are ineligible for the Kyoto Mechanisms. Based on the analysis of the various countries EIA methodologies, as presented in Appendix A, the EIA legislation in these countries would need to be amended to ensure that CCS projects are covered. In addition, companies based in countries that have not signed and ratified the Kyoto Protocol are ineligible for any of the Kyoto Mechanisms. However, such companies that register operations in a country that has ratified the Kyoto protocol, through which to run operations, are eligible.

There are other vehicles of international support for projects not eligible for Kyoto Mechanisms. For example, CSS projects will be encouraged in countries (Australia, China, United States, India, Japan and South Korea) of the Asia Pacific Partnership on Clean Development and Climate (AP6).

In summary, it is very likely that CDM/JI projects would only be validated with a full EIA. However, EIA's are not currently requested for other types of CDM/JI projects in countries where an EIA is not required by law, and the Validation and Verification Manual of the DOEs has not yet been updated.

It is therefore suggested that the following parallel activities are required to promote the concept of environmentally and socially acceptable CCS projects under CDM/JI:

- the Validation and Verification Manual be updated to include requirements for EIA in the validation of CCS projects
- national EIA legislation is amended where appropriate to cover CCS projects to guarantee that an EIA is undertaken
- both schemes to specify international guidelines should be followed
- An expert panel be created to assist host countries in developing the institutional capacity to specify requirements for ESHIA and assist in the evaluation of these to facilitate the approval and authorisation process.

4.3 Aligning requirements of CCS EIA, CDM & JI

This section draws on a DNV paper (Haefeli-Hestvik, Flach, Røed-Larsen presented at GHGT-8, June 2006). There is general consensus among many climate change experts that CCS can become a very important tool to reduce the CO_2 emission concentration in the atmosphere. Technology already exists for CCS, and some projects are already storing anthropogenic CO_2 in geological structures. Once Emission Reductions from CDM or JI Projects are issued and fully tradable, their price is expected to be close to the European Union Allowances (EUAs) which have traded at a spot price of little over €28 (as of April 2006). Therefore, such emission trading may be essential for the uptake of CCS technology. The CDM/JI mechanisms are meant to work bottom-up, to proceed from individual proposals to approval by donor and recipient governments to the allocation of verified emissions reduction. This bottom up approach creates unique opportunities for creative private developers and investors and new technologies such as CCS. This financial driver also creates an opportunity to align the requirements of the CCS EIA and CDM and JI. In many ways the requirements of the CDM fit in well with the requirements of the EIA, and the EIA is essentially part of the CDM process. If CCS does become accepted as part of the CDM process it follows then that there will be a financial driver for the EIA.

CDM/JI projects undergo many levels of scrutiny and to date no other policy instrument involves so many different stakeholders. This is especially important for CCS project. The CDM and JI mechanism have two years of good experience with multi-stakeholder involvement processes. The following figures outline the various stages of a CDM/JI project where stakeholder consultation is built in, and this is also a requirement of the EIA process. It therefore follows that if the EIA process and the CDM process are aligned, the project developers will benefit from a streamlined process that meets all the various steps that have to be followed by using a single process.

CCS projects, if accepted as part of the CDM process, will need to follow the CDM process and therefore the EIA process defined as part of it. So using the EIA process outlined in this document, which is based on best practice and universal applicability based on the countries reviewed, it follows that the EIA for CDM as defined here could be adopted as part of the CDM process. This would mean it is acceptable to host nations as well as CDM and would mean that host nations would not need to change their EIA process. The only requirement would be for the CDM to use the EHSA process defined in this document as a basis for the CDM EHSA for CCS. Because of the high transparency and global reach of the CDM mechanism, new technologies can easily be integrated and early experiences can be multiplied without the loss of integrity.

Figure 4.1 CDM validation determination process

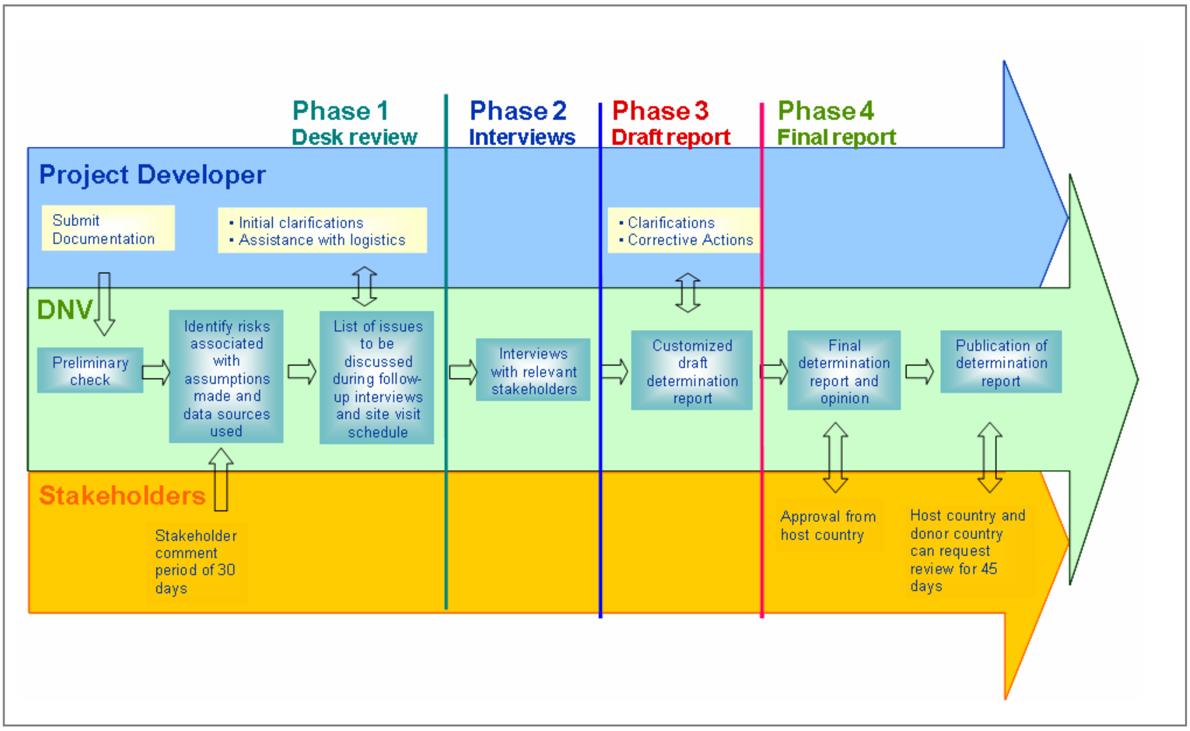
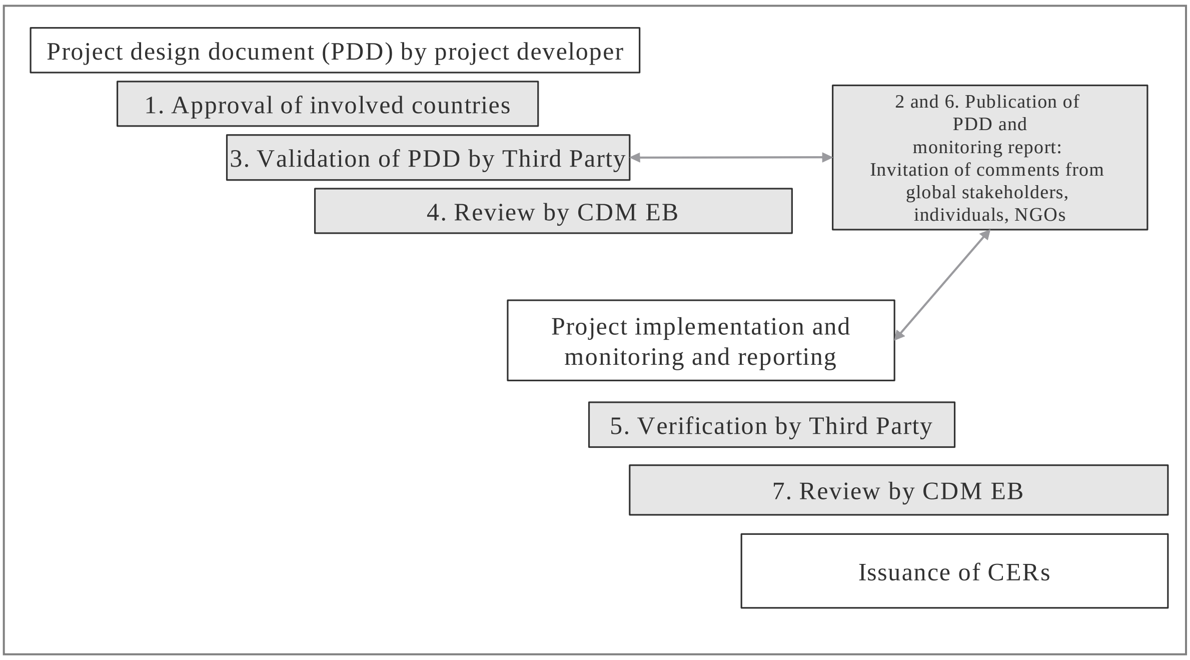


Figure 4.2 The seven scrutiny levels of a CDM project



By approaching CCS EIA in this way, it will bring uniformity to the applications that are submitted and allow for easier evaluation and comparison between projects. It will also mean that institutional capacity with in many countries with established EIA methodologies will already be in place. The CCS EIA methodology would also be best practice so all countries will benefit from a higher standard of EIA for these projects suggesting that they are more likely to survive authority scrutiny through the approval process if an EIA has been developed to these standards.

5.0 Future Trends Relating to EIA and SEA for CCS

This Chapter provides both an overview of the general expected developments in environmental assessment, in addition to some items that might be necessary to be incorporated within an EIA specifically for CCS.

5.1 General Future Trends

5.1.1 Widening of the Scope of Environmental Assessment

Glasson et al (2005) argue that there are moves to widen the scope of environmental assessments to include more fully consideration of socio-economic factors. They highlight research that indicates the fundamental issue is the trade-off between adverse bio-physical impacts of a development and its beneficial socio-economic impacts. This increased use of social impact assessment will be especially relevant for mixed use and 'sustainable' developments.

The issue is currently under debate in the UK. The Department of Health is calling for a review of the EIA process in the UK to widen the scope of impacts to be considered in relation to public health (ENDS 2006) via a Health Impact Assessment (HIA). The purpose of HIA's is to evaluate whether projects could be responsible for reinforcing existing health inequalities or damage the pertinent populations' health. The Department wants to incorporate HIA into the EIA process or if this is not possible to establish a mechanism for determining when a separate HIA is required. At present health issues should be taken into account, however there is reported to be an absence of a systematic approach to the use of HIA's. Current EIA's could cover health impacts but they rarely include consideration of wider social and psychological elements (ENDS 2006).

The HIA process is often done in parallel with the EIA process and treated and presented separately (DNV-IEMA telecom). This trend is expected to continue but there is the possibility of increased application of HIA/EIA for projects that have greater potential health impacts i.e. nuclear and incineration projects.

On the whole environmental statements tend to be increasing in size as more issues are being addressed. The inclusion of health, social and sustainability assessments will add to this unless scoping is used effectively to focus the EIA upon likely significant effects only. The value of integrating these various assessments into one for CCS is however desirable as it will promote economic efficiency as well as more informed decision making.

The World Bank (WB) is a good example of an organisation that has widened the scope of EIA, even changing the terminology to Environmental Assessment (EA) because of consideration of the project from "cradle to grave". The WB has ten safeguard policies, six of which are environmental, two social and two legal. These are all incorporated into the EA process through project tailoring of social analysis ensuring that the relevant social aspects are considered for each project (DNV-World Bank telecom 2006). HIA's however, are only done on larger projects where a clear impact on health is visible e.g. in the case of HIV AIDS. If a cause-effect relationship is identified during the scoping process, then a HIA will be carried out to examine the potential health affects.

In the case of CCS projects where a significant release of CO_2 could happen with a concomitant impact on health it follows that an integrated environmental health and safety impact assessment (EHSIA) approach would be appropriate if linked to a risk assessment to prioritise risks and likelihood of realising impacts.

Integrated environmental assessment was first raised in the mid 1990's (Glasson et al), and it is predicted that there will be increased moves towards this approach in the future.

5.1.2 Development in the Nature of Methods of Assessment

Glasson et al (2005) argue that impact prediction methods as they stand can raise technical and conceptual problems, for example: difficulties associated with determining how the environment will evolve if the project were not to be developed; difficulties associated with determining complexity of interaction of impacts. These authors highlight research by a number of people into the development of novel methods to assist with impact prediction and to remove some of the uncertainty associated with the process, for example matrices, checklists and mathematical models.

5.1.3 Developments in Consultation

Consultation with interested and affected parties is often not presently particularly effective in Europe (Glasson et al 2005). There are currently varying levels of access to the consultation process. Glasson et al describe the process as "too little and tokenistic" and they question whether access to the process should be improved. They point out that many believe the EIA process to be too developer-oriented in particular, because the developer uses or hires their own expert to carry out the EIA and prepare the EIS. The authors conclude that this is unlikely to result in an unbiased report on the predicted impact of the project. Counter-arguments to increased consultation relate to the cost and delays associated with greater participation/ access to the process (Glasson et al 2005).

There has been a call for a move to ensure that the public contributes more to the Environmental Assessment (EA) process at the SEA stage. It has been proven that the earlier the public are engaged in the process, the easier it is to engage them and get results from their engagement. Thus, to ensure that public participation is meaningful and can effectively contribute to the overall objective, EA legislation has to promote a process that provides for extensive front-end consultation as a means to encourage a cooperative and ongoing approach to EA (Doelle, 2005). To this end, a fundamental shift in the point of public engagement is required which means increased public consultation at the SEA stage. There are however, many hurdles that need to be overcome before this shift is reached, such as identifying the public/stakeholders/interested and affected parties and the processes for engagement.

The Aarhus Convention and Public Participation Directive will increase public participation requirements in the EU in the near future.

5.1.4 Mandatory Post Implementation Monitoring

Mandatory monitoring is absent from many EIA and SEA frameworks. Glasson et al argue that the extension of mandatory monitoring is a current issue up for debate. Mandatory monitoring is in place in certain places for example California and Western Australia, however in many places the one-off nature of many projects acts as a disincentive to developers monitoring or auditing the quality of their assessments and predictions.

It has also been suggested that more attention be given to socio-economic issues in the follow-up stages, as often, when post implementation monitoring is done, the focus is all on the environmental factors. Socio–economic follow up may enhance public tolerance and support of projects, as well as building trust and credibility among stakeholders in the EIA process (Morrison-Saunders, 2005).

5.1.5 Consideration of Cumulative Effects

Glasson et al describe many projects as “individually minor” but collectively they could pose a significant threat to the environment and health. Consideration of cumulative effects is included in many frameworks but Glasson et al argue that in practice assessment of cumulative effects can be problematic and deficient. A number of countries/ organisations have issued guidance on the issue e.g. the Canadian “Cumulative Effects Assessment Practitioners Guide”. However whilst in theory it needs addressing, in practice there can be problems associated with who is responsible for requiring or commissioning a cumulative environmental assessment because often more than one competent authority could be involved when numerous projects are to be considered.

Cumulative effects of socio-economic issues are also falling into the spotlight as specialists review the EIA process. The range of socio-economic considerations should include broader concerns beyond the obvious and direct project-level impacts such as regional scale issues and cumulative effects (Morrison-Saunders, 2005).

5.1.6 Consideration of Sustainability Issues

Sustainable development is an issue that is gathering increased expectation to be considered in EIA and SEAs. Often SEAs are primarily seen as information tools and at present would not prevent what could be perceived as unsustainable development. Increased use of sustainability appraisals, often done in parallel with EIA projects is seen as becoming a future requirement in EIA (DNV-IEMA telecom, 2006).

There is reported to be concern that human and social aspects of sustainability tend to be underplayed and that health impacts in particular are not given sufficient consideration in EIA or SEA. There is an initiative that specifically requires developers to include a Sustainability Statement in the planning documentation submitted for planning consent review. The initiative is believed to merit further investigation in order to determine whether it warrants wider application.

It has been suggested that SEA is going to develop into a tool for assuring the environmental sustainability of plans and programmes, based on a check list approach (Fuller, 2004). This has emerged from an increased use of Sustainability Impact Assessment (SIA) and an increased emphasis on social and economic issues which calls for some form of sustainability assessment at the SEA phase. SIA is similar to SEA, but it includes economic and social inputs, providing a critical evaluation of the performance of a Plan against predetermined social, economic and environmental criteria so that the Plan's performance can be improved (RTPI introductory guide to planning and environmental protection). Further incorporation of SIA into SEA is expected in the future.

5.1.7 Narrowing of frameworks and regulations

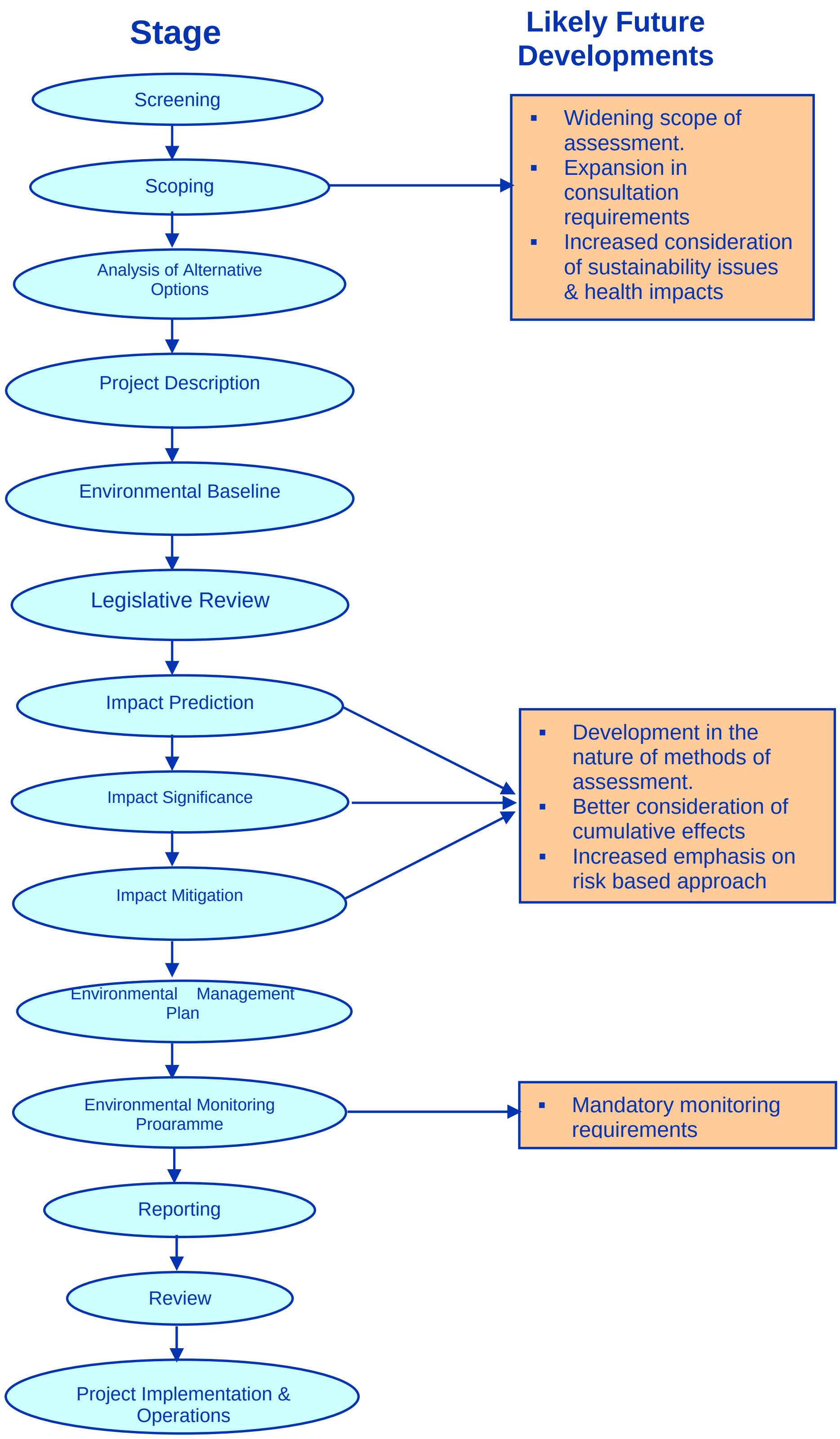
Often it is difficult to implement SEA requirements because of the need to improve practical guidance on how to conduct an SEA. The broad nature of SEA means that many authorities are not attaining optimum results and are often unsure of the SEA process itself. Thus, in the future, there will be a possible move towards streamlining the SEA process and ensuring that the fundamentals are understood before adding too many other components to the equation.

5.1.8 Early consideration of environmental and socio-economic issues

As individual countries develop and their SEA processes move towards a formalised system, it is likely that there will develop a more integrated approach to decision making incorporating the environment, social and economic aspects, with the aim of this being applied to policies at the highest level (Fuller, 2004). There are however, many barriers to this process such as intangible policy formation that will need to be overcome if the move towards SEA of policies is to be achieved.

Figure 5.1 below highlights the stages of the EIA process where these future potential developments in environmental assessment will need to be considered.

Figure 5.1: Assessment Stages & Future Developments



5.2 Elements Specific to CCS projects

5.2.1 Integrated Environmental Health & Safety Impact Assessment EHSIA

In the case of CCS projects where a significant release of CO_2 could happen with a concomitant impact on health and safety (e.g. onshore CCS projects), it follows that an integrated environmental health and safety impact assessment (EHSIA) approach would be appropriate if linked to a risk assessment to prioritise risks and likelihood of realising impacts.

5.2.2 Risk and Uncertainty Basis for CCS EIA

It is the role of the EIA for CCS projects to identify any predictable risks or uncertainties that could cause the project to be abandoned. This widens the scope of standard EIAs and is required, because CCS projects are carried out for long term global environmental benefit and abandoned projects could result in reduced positive or negative environmental impact. So, CCS EIA should assess more than just the pure environmental risks; they must also demonstrate, at a high-level, that all projects risks are being managed appropriately.

With the development of CCS projects, the development phase means that projects will start with a negative carbon balance owing to short term local impacts. Abandonment after this stage, without any injection, could be expected to result in a large negative carbon balance, totally at odds with the environmental objective of the project.

Project risks and uncertainties can be assessed via various approaches, although the effective approach is often a brainstorming workshop approach. These workshops are often best independently facilitated and follow a standard risk assessment process.

A number of essentials should be considered when risk assessing CCS projects:

- that the requirements and expectations of all stakeholders are understood
- that all categories of risk and uncertainty are assessed
- that risks are assessed by teams with the appropriate competence
- that risks and uncertainties are assessed for all phases of the project, including post-injection.

An example of a possible structure for risk assessment for a CCS project is provided in Appendix D.

Risks and uncertainties should be assessed as they currently are with existing controls and contingency plans. Recommendations should be put forward as appropriate.

One option for the development of CDM projects is the requirement of CCS Developers to purchase credits to cover emissions during development phase. Under such an option, there is less need for a full strategic project risk assessment, because although early abandonment of a project will result in environmental impact, it will be accounted for and require reductions against a countries baseline if it is covered by one of the trading schemes or Kyoto mechanisms.

5.2.3 CCS Carbon Balance

The EIA process and triple bottom line approach was developed as a way of encouraging a balanced perspective between economic, social and environmental interests, risks and impacts. The EIA has generally been used to safeguard the environmental interest in the face of normally highly positive economic and a range of socially beneficial impacts. Under these circumstances, potential environmental impacts have normally been negative on balance, and cost projects varying amounts of capital to manage. This cost has been accentuated further by the increasing emphasis on internalising the cost of environmental pollution and impact through ideas such as the polluter pays, IPPC and BAT. These approaches have generally impacted on the economic bottom line of projects whilst improving the balance on social and environmental impact. So mitigating environmental impacts has generally cost significant money.

In CCS projects the scenario is rather unusual in that there will be a possible significant positive environmental, social and economic impact amongst some potential negative impacts, and that the environmental benefit is linked to the financial gain derived from the project. In this sense, the environment is central to the process of capital gain and is not just a cost. Having said this, it should follow that all projects are beneficial and should occur if there are no other significant negative impacts. It should however be borne in mind that although there is benefit there is also a carbon cost in preparing, operation and closing down CCS operations. To evaluate the carbon benefit of CCS a carbon balance needs to be considered as part of the EIA process. Just as an EIA may ask for an energy balance or a water balance, so it is important to do a carbon balance for CCS. The table below provides a basis, and requires further development, for a carbon balance for CCS projects.

Table 5.1: Minimum Carbon Balance

Carbon Benefit	Weight of CO_2	Carbon Cost	Weight of CO_2
Amount of CO_2 stored (totals for entire life of operation):		Amount of CO_2 produced (totals for entire life of operation):	
Establishment		Establishment	
		Reservoir characterisation Reservoir establishment and preparation for CO_2 receipt Capture equipment manufacture Capture equipment installation Pipeline manufacture Pipeline installation	
Operation		Operation	
Minimum reservoir CO_2 capacity or Anticipated CO_2 reservoir capacity		Capture equipment operation Pipeline operation Injection operation Monitoring operation	
Closure		Closure	
		Decommissioning capture, transport and injection assets Infrastructure removal and disposal	
Liability		Post Closure	
		Post closure monitoring programme	
EOR		**EOR**	

EOR operation CO_2 stored		Additional CO_2 emissions from incremental hydrocarbons EOR operation CO_2 losses to atmosphere EOR operation	
		Leakage	
		Amount of CO_2 to estimated to be lost to atmosphere (Risk based estimate)	
Sum of total amount of CO_2 stored		Sum of total amount of CO_2 to atmosphere	

Ratio interpretation

1:1	no benefit
0.x:1	no benefit
1:0.x	Carbon beneficial

The EIA is not the same as the CDM boundary that may be selected and the two must not be confused. Under the EIA there is no boundary so the full impact of the project can be revealed. Under CDM project boundaries, a convenient accounting process is defined which may not include any extra emissions created. It is important that it is transparently shown whether or not projects will actually provide a carbon advantage.

The boundaries of the project are therefore of great importance in determining what CO_2 should be counted in and what should be excluded. It is important to bear in mind that the intent of CCS is to reduce the accumulation of additional CO_2 in the atmosphere. Therefore any activity that reduces CO_2, on balance meets this intent, but it should therefore also include all the CO_2 that the activity produces. The various delegates at a recent workshop to discuss the relationship between CCS and CDM reported the following summary notes.

On the definition of project boundary, participants generally concurred that the project boundary should include capture, transport, and injection and storage, and that this could be handled with few difficulties under the existing CDM framework. There was some disagreement, however, as to whether CCS projects whose project boundary spans more than one country should be included under the CDM at this time.

Participants then debated whether increased carbon dioxide emissions resulting from CCS should be considered as leakage. Differences emerged over the inclusion of enhanced oil recovery (EOR) projects under the CDM, with some arguing that EOR leads to increased oil extraction, which counteracts the sustainable development goals of the CDM. Regarding additionality and EOR, a number of delegates argued for a case-by- case assessment.

Earth Negotiations Bulletin Vol. 12 No. 302, 23 May 2006 (ENB Vol. 12 No. 302 UNFCCC SB 24 #6).

In the carbon balance proposed above all activities are included from the initial project proposal, site development infrastructure development till its removal at closure and also to include the CO_2 cost of long term monitoring. In essence, a complete carbon balance that accounts for all the CO_2 that will be stored and produced as a result of project activities. The balance, in support of the CCS intent, also includes the CO_2 lost as a result of the EOR activities, where applicable, and then also the additional CO_2 value for the hydrocarbons produced as a result of EOR. This will make EOR projects less desirable from one perspective but from an alternative perspective it will merely mean that the minimum size of a reservoir that will be used has to be larger, i.e. more capacity to store CO_2. In essence this carbon balance then becomes a size determiner of CO_2 storage capacity to ensure that the amount of CO_2 that is produced as a result of overall development is significantly less than reservoir capacity to ensure that advantage is gained in reducing global atmospheric CO_2 concentrations. The risk assessment (Section 7.3) associated with the leakage potential of the reservoir is therefore a fundamental part of the carbon balance and therefore the proposed methodology for the environmental assessment.

5.2.4 Project boundaries and impact boundaries

Although the EIA will need to cover capture, transport, injection and storage through all phases of development and construction, operation, closure and decommissioning and long term monitoring of a project, it must be borne in mind that this refers to the activity phases of the project (project boundaries) and not the environmental impact boundaries.

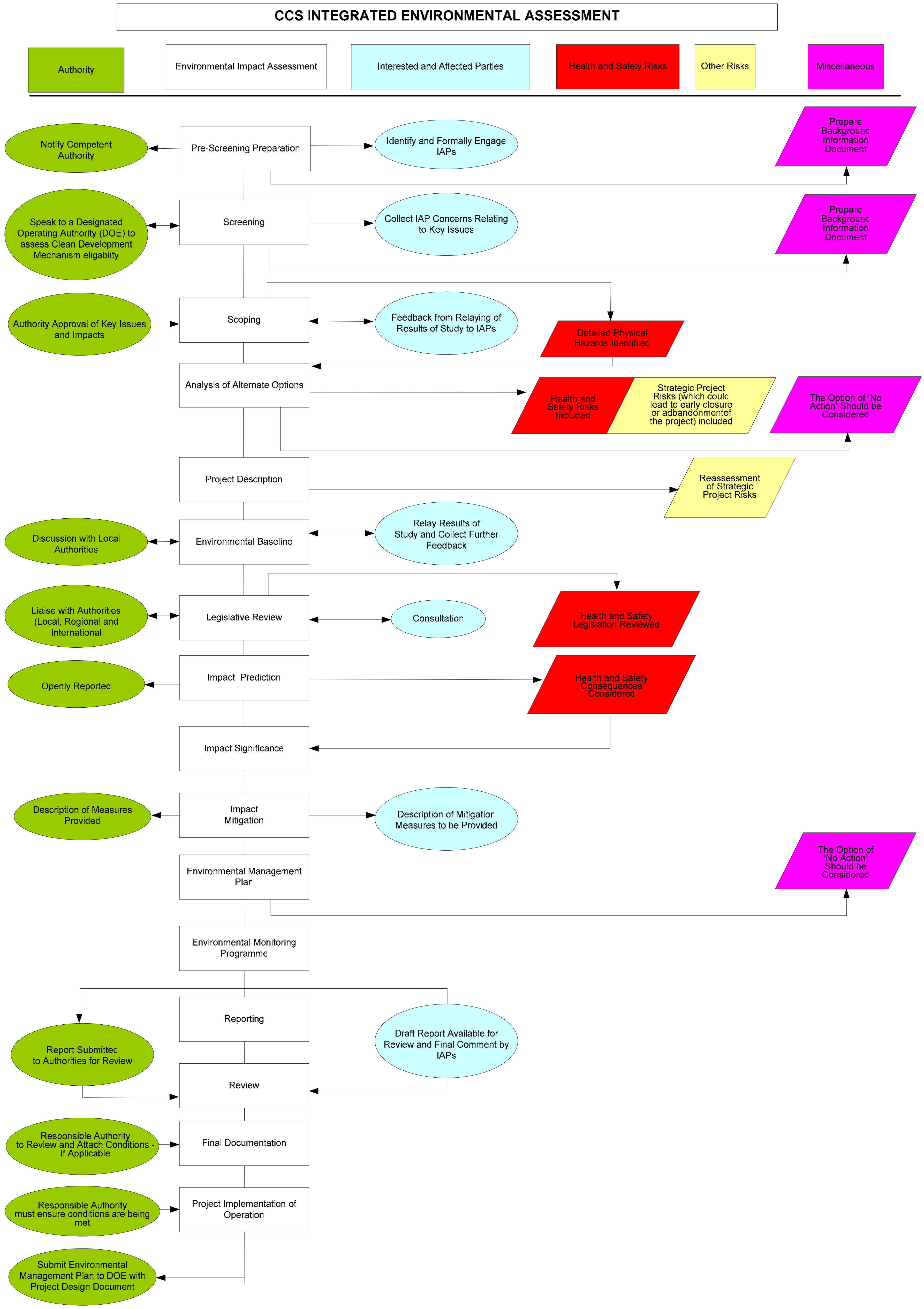
Project boundaries are likely to be far smaller than impact boundaries as the receiving environment and individuals are mobile and the pathway to the receiver of impacts is potentially mobile too; as an example if CO_2 leakage occurs from an offshore reservoir then there will be CO_2 leaking into the water which is mobile so the receiving environment can extend beyond the boundaries of the project. In the same way for example, plankton that are affected by leaking CO_2, directly or indirectly, could become less available for supporting other organisms which could be down current from a reservoir. It is therefore important not to restrict the impact assessment to the project boundaries, but to look at the full extent of the what impacts can occur where as a result of direct and indirect effects from CO_2 or the operations associated with a project. The impact assessment boundaries would therefore extend beyond the activity based project boundaries used in CDM.

5.2.5 Ideal CCS EA Methodology

Considering the best practice approach, the trends in EIA development, the emphasis required on selecting low leakage potential reservoirs with long term stability, specific CCS decision support requirements and the overlap with other mechanisms such as CDM and JI the CCS methodology for EIA, it follows that the philosophy underlying EIA needs to be modified for CCS, to encompass a more integrated approach incorporating risk, safety and health.

Figure 5.2 overleaf proposes the assessment approach most suitable for CCS projects based on good practice for EIA from various countries, specific input requirements for CCS projects as noted in this section and the requirements from CDM. The environmental elements of this approach are discussed further in Section 6.4.

Figure 5.2: Flow diagram illustrating integrated nature of assessment



6.0 Information Requirements for EIA & SEA - General

6.1 Introduction

This chapter, and the next, consider information requirements for environmental assessment of CCS projects, assessing whether sufficient information exists to complete an EIA, and where this is not the case, identifying the gaps and research needs to fill those gaps.

Most of the information relating to a CCS project and its environmental assessment is available for the above ground, more established, practices and technologies, but as consideration moves to the injection of CO_2 into the reservoir below ground and beneath the sea bed, available data, information and techniques are less well established. On this basis a separate section (Chapter 7) is dedicated to discussing these issues and gaps in more detail.

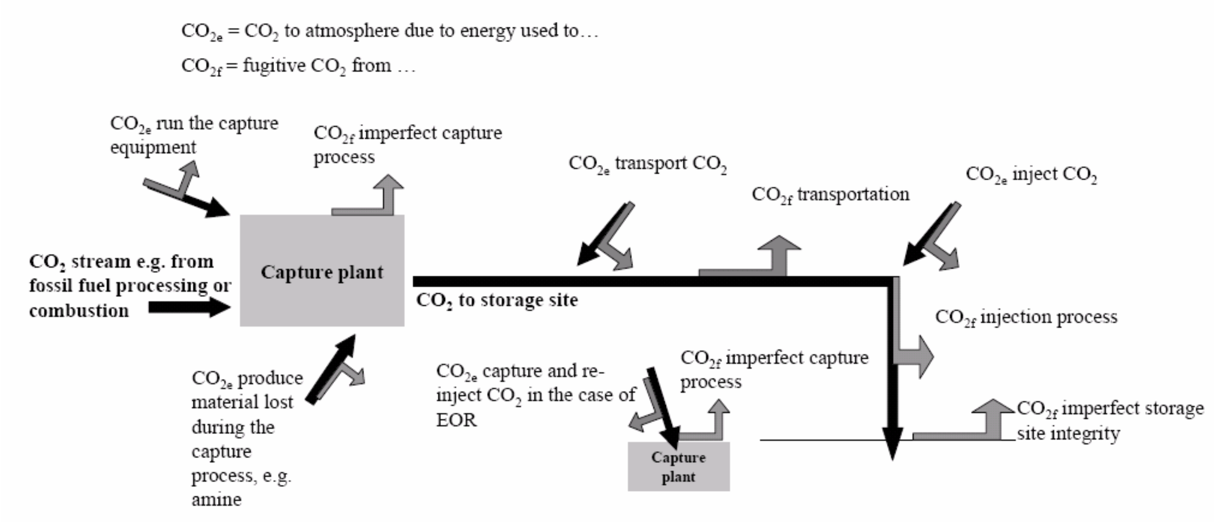
6.2 Stages of a CCS Project & General Availability of Information

CCS essentially comprises three stages – capture, transport (via pipeline) and injection and storage in an underground reservoir. A schematic of the CO_2 CCS process is provided in Figure 6.1. Note that although the figure focuses on CO_2 emissions, it is important to remember that a CCS project will also have other concerns, such as noise, waste, wastewater, groundwater pollution, impacts on ecosystems and habitats, purity of CO_2 etc.

The following discussion summarises the various items/issues associated with each stage, noting the following elements:

- Black arrows – indicate CO_2 emissions due to energy consumption
- Grey arrows – indicate fugitive CO_2 emissions due to leaks

Figure 6.1: Stages of Carbon dioxide Capture, Transport and Storage



Source: Haefeli et al, IEA, 2004

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6.2.1 CO_2 Capture

Carbon capture is the process by which the principal CO_2 process streams from (e.g.) fossil fuel processing or combustion, which would otherwise be discharged to atmosphere, are captured via some form of 'capture plant'. In so doing, however, the actual capture equipment – which itself requires energy input to operate – also generates both direct CO_2 emissions, and indirect fugitive CO_2 emissions due to equipment leaks etc. At the same time, CO_2 emissions are produced via materials (e.g. amines) and are lost during the carbon-capture process. There are also likely to be CO_2 emissions generated through inefficiencies and imperfections in the capture process. Nevertheless, once these CO_2 emissions are captured, they must be routed to final storage. It is also important to bear in mind that it is unlikely that the CO_2 stream will be 100% pure or devoid of other chemical pollutants and that the operation not only captures and produces CO_2 but also a range of wastes, by-product gases and sludge which in their own right can cause environmental impacts if not managed.

It is considered that the information necessary to undertake an assessment of the capture technologies is well developed and as such does not have significantly different needs than the many EIA's conducted every year. This stage will result in additional noise, air emissions, waste generation etc, all of which are relatively well defined (IPPC, Benson and Cooke, 2005) and all of which are issues typically assessed in an EIA. For example, the additional NOx and SOx produced will require air quality modelling, which has standard well established techniques with numerous models commercially available and accepted by environmental regulators worldwide.

Additional R&D is needed however, to improve knowledge of emerging concepts and technologies for CO_2 capture, in particular to help demonstrate the reliability of the environmental performance of capture systems on a large scale.

6.2.2 CO_2 Transport

Following the CO_2 capture stage, the captured CO_2 must undergo some compression and be transported via pipeline with pumping to the final injection and storage site. Transporting the captured CO_2 will itself generate additional CO_2 emissions due to energy use associated with pumping etc. Additionally, there are likely to be some fugitive CO_2 emissions generated and associated with point-source and accidental leaks along the transport train.

It is considered that the information necessary to undertake an assessment of this stage of the CCS project is fairly well defined, and does not have significantly different needs than for the many EIA's conducted every year, and does not involve technologies significantly different from those which are well established and in commercial use today. This stage will result in noise, fugitive air emissions (leaks), waste generation etc, all of which can be relatively well defined by engineers and all of which are issues that are typically assessed in an EIA.

One area where there is currently a gap in knowledge is in dispersion modelling of supercritical CO_2 releases, if they were to occur, whether from pipeline or reservoir.

6.2.3 CO_2 Storage

The storage stage may require further compression and CO_2 injection into the geological reservoir, which could be onshore or offshore, for long-term storage. Again, besides the principal CO_2 stream to be injected and stored, compressing the CO_2 will itself generate additional CO_2 emissions due to energy used by the compression equipment. As this process step is high-pressure, there are also likely to be fugitive CO_2 emissions associated with valve and flange leaks etc. Following compression, the CO_2 will be in a high-pressure gaseous state (supercritical), and will be injected under pressure into a suitable geological storage formation (e.g. a voided or depleted former oil and gas reservoir or a saline aquifer). Again, there are likely to be fugitive CO_2 emissions (i.e. leaks) generated during the injection process. Moreover, the CO_2 reservoir itself may not provide perfect storage, as 100% site integrity may not be achieved over a very long-term scale.

It is considered that the information necessary to undertake assessment of the compression stage is well defined, and does not have significantly different needs than for the many EIA's conducted every year, and does not involve technologies any different from those well established and in commercial use today. This stage will result in noise, fugitive air emissions (leaks) etc, which can be relatively well defined by engineers and which can easily be assessed in an EIA.

However, it is considered that the information necessary to undertake environmental assessment of the injection and storage of CO_2 stage of a CCS project is not well defined, and has many uncertainties. The uncertainty relates mainly to the carbon dioxide leakages, whether from faults, well blow outs, cap leaks, poor injection etc. In many cases the likelihood of such leaks and their size is not well defined.

As this area is poorly defined it is considered separately in Chapter 7 where a more detailed discussion is presented.

6.3 SEA and Site Selection

SEA is applied at an earlier stage in a CCS development than EIA, and as such is a key tool in sustainable development strategic decision making. CCS will ultimately be guided by national and international policy decisions regarding the relative importance placed on GHG mitigation – and the role of CCS within this national framework – within the overall context of a country's national environmental priorities.

Clearer regulatory guidance is necessary on, e.g., the play-off in priorities between local pollution concerns versus climate change concerns (e.g. sea level rise, global warming, severe storms etc) using some form of 'risk-benefit' approach. SEA should be used when strategic-level decisions are being made – i.e. when alternative options are being evaluated and the preferred option(s) chosen or when identifying the most optimal locations for CCS. The SEA framework can also be utilised at the beginning of the process when potential CCS sites are being identified and compared. The SEA is a higher level strategic study so should generally not require extensive detail, though some level of technical detail will be required to identify potentially viable sites.

Whilst general SEA guidelines exist, SEA guidelines and 'best practice' as needs to be applied for CCS, do not currently exist. These guidelines will need, at least, to be a blend of:

- Technical knowledge associated with reservoir storage integrity, reservoir engineering and other related geosciences to determine structural and stratigraphic potential and opportunities for trapping of separate-phase CO_2 below low-permeability caprocks.
- Technical knowledge associated with CO_2 lateral migration potential associated with hydrogeology, residual CO_2 trapping, solubility trapping and mineral trapping so that potential sites with secure storage over geological timescales can be broadly identified.
- Broad sustainability, environmental, social and economic knowledge to determine the extent to which CCS will meet and mitigate the national drivers for management of CO_2, sustainable economic development (through potential licensing, industrial support and employment creation, etc), social development (through institutional capacity building, education, legislative framework development etc), social acceptance of CCs and its implications; this is dealt with in more detail below.
- Strategic and logistical knowledge relating to the sources (location, operational life, quality of CO_2 feed etc), transport systems (pipelines, tankers etc) and the support necessary to ensure CCS is feasible. This understanding will come from analysis of the proximity of major CO_2 sources to suitable storage sites, facilitating decision-making about large scale deployment of CCS (IPCC 2005). Detailed regional assessments are required to evaluate how well large CO_2 emission sources match suitable storage options.
- Broad institutional and national regulatory knowledge to determine the extent to which CCS will require changes to the law relating to authorisation and permitting in the short, medium and long term; monitoring, ownership, management, mitigation management financial capacity and mechanisms etc. This institutional analysis will also require assessment of the institutional capacity to support CCS activities and the level and nature of CCS expert panel support that will be required. Part of this analysis should be to determine if the EIA framework presented here can be used for CCS within the national context and how mechanisms such as CDM and JI can be advanced through CCS activities.
- Clear guidance is necessary to advise on the play-off in priorities between local pollution concerns versus climate change concerns, and the balance between leakage risk and impact upon the atmosphere. This balance may shift with time with the increasing quantities of CO_2 stored underground, set against the (hopefully) decreased risk of leakage owing to increased experience.

Most of the environmental issues relating to CCS overlap with the engineering issues, as both have the primary requirement for ensuring that CO_2 remains in the storage reservoir for hundreds to thousands of years without significant leakage. As the two issues of engineering and environment are so inter-related, it is considered that this could be addressed from a strategic environmental perspective through the creation of minimum national or international standards and requirements for site selection (storage reservoir), that include:

- Geology
- Seal Thickness and Integrity
- Fluid Compatibility and potential geochemical reactions
- Reservoir Properties Assessment
- Disposal Well Selection
- Well Modelling
- Well design, primary cementing, materials quality, corrosion, monitoring, abandonment
- Failure of wells and pipelines
- Surrounding environment
- Lateral migration potential.

These minimum standards would then be considered in any SEA assessment, whether on a national or regional basis, in order to highlight areas that might be acceptable for CCS and rule out areas that should not be considered for CCS. Such consideration would need to be done in conjunction with national bodies' environmental targets and priorities. The minimum standards would need to be used in tandem with good operational and monitoring procedures.

It should be noted that the generic standards will have limitations in the level of protection they can achieve, because each individual CCS site will have different characteristics.

Vattenfall (2005) conducted R&D on CCS issues, and prepared a paper that considers SEA to assess environmental impacts of the following CCS alternatives:

- Environmental analysis and comparison between power plant alternatives with and without CCS, including consequences of increased coal mining following the introduction of CCS.
- Environmental consequences of CCS compared to 'no action'.
- Comparison of environmental effects associated with different technical alternatives.
- Comparison of environmental consequences from a long term low leakage rate scenario, a short term high leakage rate scenario and a scenario where the concept works according to plan without leakages.
- Comparison of the magnitude and significance of different environmental consequences relating to CCS.

The valuation was carried out using two parallel methods that complement each other – impact matrices and SWOT analysis. CCS is still a relatively new concept, and as such, available data was sometimes incomplete or uncertain, so absolute conclusions were sometimes based on qualitative data.

It was concluded that provided the concept of CCS works according to plan without leakages, that no major environmental effects are expected from the storage component. This emphasises the fundamental requirements of careful site selection, and good operational and monitoring procedures as discussed above. The role of the SEA in creating the right level of understanding and context for CCS before EIA are undertaken, is highlighted and of paramount importance.

6.4 Best Practice EIA

Figure 3.1 presents a best practice environmental assessment framework, as extracted from the right hand column of the spreadsheet in Appendix A; it represents a combination of the good practice elements from different countries around the world.

It is against this proposed EIA framework that the EIA methodology for CCS projects could best be formulated. Countries could use this as a template for their own national EIA process for CCS. It is probable that a framework such as this will be required under CDM. In all cases this proposed CCS EIA framework is a greater or equal requirement than existing national legislation. This will ensure that the complexity and long-term nature of CCS operations and the application of new science and engineering is adequately covered and risk assessed.

In the table below, the different best practice EIA stages and the information requirements for CCS EIA projects are assessed in terms of whether sufficient information currently exists to undertake an EIA.

As mentioned earlier, because the CO_2 injection and storage stage of a CCS project is not well defined and has many uncertainties relating primarily to carbon dioxide leakages, it is considered in Chapter 7 in more detail.

Table 6.1: EIA stages for CCS projects and Gaps in Information

STAGE.	DESCRIPTION.	INFORMATION REQUIREMENTS & *GAPS*
Screening	Screen to determine whether or not the project requires an EIA. Consultation with interested parties, governments or authorities as required.	Because of the nature of CCS, it is unlikely there will be any small scale projects that do not require an EIA, and there seems little point in setting a threshold size of project below which an EIA is not required. One exception might be pilot scale plants, and this needs to be clarified.
Scoping	The aim of the scoping process is to determine the items and issues to be addressed in the EIA (terms of reference). The developers should outline the methods to be used in the course of the EIA. Interested and affected parties should be given the opportunity to comment on the scope of the EIA.	Scoping of issues would need to include all the CO_2 releases illustrated in Figure 6.1, some of which are poorly defined as discussed in Chapter 9. Additionally, scoping would need to include all other environmental issues such as noise, NOx, SOx, construction aspects, amine waste generation, all of which are more typical issues usually considered in an EIA, and no gaps are likely in this regard. EIA guidelines when produced should be followed and should identify the minimum scope of issues to be addressed. The EIA should identify the environmental resources to be covered in an EHSIA, and the specific information that, as a minimum, should be included under each environmental resource based on the risks identified in this report. With regard to EOR, it needs to be clarified if CO_2 emissions from the incremental recovered as part of the project would need to be assessed in an EIA. It also needs to be clarified in EIA guidelines what type of accident scenarios need to be considered and assessed in an EIA in addition to consideration of small leaks. In relation to techniques, it is recommended that EIA risk assessment guidelines are drawn up with proposed methodologies for assessment, particularly with regard to potential CO_2 releases from the reservoir.
Analysis of Alternative Options	Developers should include a description of the alternatives to the proposed project. The description should include an assessment of the potential impacts and potential mitigation. Consideration should be given to the option of "no development".	This would need to be set in the context of the SEA, and minimum requirements for site selection which are not currently available (see Section 6.3).
Project Description	The developer should include a comprehensive description of the project in the EIA. The description should cover the lifecycle of the project (i.e. construction, operation, maintenance, decommissioning). It should include an	There are no knowledge gaps anticipated in being able to provide this information. However it should be set in the context of the SEA, for which there are currently no guidelines providing minimum standards for site selection. A carbon balance is recommended to be undertaken (see Section 5.2.2) to ensure

STAGE.	DESCRIPTION.	INFORMATION REQUIREMENTS *& GAPS*
	overview of: size, location, timetable of the project, proposed land use, nature and quantity of construction materials, description by type and quantity of the expected residues and emissions (noise; water; air; soil pollution; vibration; light; heat etc) and anticipated ownership and responsibility for the life of the reservoir..	the benefit of the project with regard to climate change. This will essentially set the minimum size of projects as those proposals which do not have a significant CO_2 storage/production ratio will not further the intent of CCS.
Environmental Baseline Review	The objective of the baseline review is to describe the state of the environment as it is prior to commencement of project operations. The review should describe the flora & fauna; water aquifers; geohydrology, water courses; shore lines; existing discharges; soil; geology; geomorphology; including seismic characteristics; cap rock characterisation, air (quality; climatic factors); architectural, historic and cultural heritage.	Baseline review is likely to be similar in some respects to the requirements for offshore oil developments. However, full knowledge of CO_2 sensitive organisms is required and presently, knowledge is too limited in many instances to be clear on what baseline studies are necessary (see Section 7.6). Note: the baseline for proposed offshore developments will also need to include onshore areas where appropriate. Future EIA guidelines should specify the typical baseline studies that would be expected. The baseline report would need to include details of approved future land-use development to be taken into account in the assessment.
Legislative Review	Developers should include in the documentation an outline of the policy, legal and administrative framework within which the EIA is prepared It should include all relevant legislation at a local, state/ territory, regional, national and international level that could affect the proposal. Also, development of a CCS site should not conflict with other legislation.	Many of the necessary legislative frameworks are not currently in place for CCS projects – although studies are underway to solve this problem. Gaps in legislation relate to material requirements, operational requirements, safety requirements, selection of pipeline routes, selection of reservoir, liability etc. Separately, it is also necessary that development of a CCS site should not conflict with other existing legislation, and it may be necessary to amend some legislation to enable CCS projects to go ahead. For example, at the international level, movement is underway to eliminate legal barriers to CCS and provide an enabling environment for the technology. These include the OSPAR Convention, IPPC, Groundwater & the Landfill Directive. Note that storage of CO_2 under the seabed will be allowed from 10 February 2007 under amendments to the London International Convention and Protocol, which governed dumping of wastes at sea. The OSPAR Convention, which provides further protection to the marine environment of NE Atlantic, is expected to follow suit. Additionally, in the EU, CO_2 is currently likely to be considered as a "waste", which would prohibit it being stored underground onshore under the EU Landfill Directive. Studies are underway to resolve these regulatory issues such that legislative barriers to CCS can be overcome without exposing the environment to unacceptable risk.

STAGE.	DESCRIPTION.	INFORMATION REQUIREMENTS *& GAPS*
Impact Prediction	The impacts identified in the preceding stage should be quantified via qualitative, quantitative and semi-quantitative techniques. Developers should consider frequency, duration, magnitude, risk etc.	For the issues identified under "scoping", the techniques and data for predicting and assessing impacts are generally available and in existence for carbon capture and transport. For storage, however, further information will be necessary (Chapter 7), as (e.g.) modelling will need to be proven in relation to CCS. Impacts need to be assessed against the context of the baseline, which should include future approved planned developments. Additionally, the potential for the project to "sterilise" land-use potential should also be discussed, although this will prove difficult in relation to potential future developments set 100's of years into the future; some way to address this needs to be developed.
Impact Significance	In determining the significance of activities, developers should consider the size of the project; location (near Sites of Special Scientific Interest); and the nature of the effects. Impacts should be screened and prioritised accordingly.	The techniques and data for assessing the significance of impacts are generally available and in existence in relation to carbon capture and transport. However, for storage, further information will be necessary (Chapter 7), such as (e.g.) knowledge of the effects of CO_2 on marine ecosystems is currently limited.
Impact Mitigation	Developers should provide a description of the measures which will be taken to avoid; reduce; or remedy significant adverse effects. The description should include an overview of the predicted or expected cost effectiveness of the measures; the statutory or policy basis of the measures; cost of mitigation.	The techniques and data for mitigating impacts are generally available and in existence in relation to carbon capture and transport. But for storage, further information will be necessary (Chapter 7), as mitigation techniques in use in the field of oil and gas will need to be proven in the sphere of CCS.
Environmental Management Plan	The environmental management plan should contain a framework for the continuing management and mitigation of the project including consideration of who will be responsible.	The information for developing an EMP is generally considered to be available, but would need to cover issues related to liabilities and responsibilities over the long term (see Chapter 8), which are currently not defined fully. Mechanisms for financial provision for mitigation and management in the long-term will need to be detailed to ensure adequate resource capacity exists for long term management and monitoring.
Environmental Monitoring programme	The environmental monitoring programme should provide a detailed programme for monitoring which is appropriate to the nature, location and size of the storage reservoir. Developers should consider the nature of monitoring techniques to be used (there may possibly be minimum standards for pipelines).	The information for environmental monitoring is generally available in relation to carbon capture and transport because the techniques that the literature suggests could be used are those that are commonly employed to monitor pipelines by the oil and gas industry. But for storage, further information will be necessary (Chapter 7), (e.g.) mature monitoring technologies would need to be demonstrated as applicable for CCS, and further R&D is necessary for some monitoring technologies in early stages of

STAGE.	DESCRIPTION.	INFORMATION REQUIREMENTS *& GAPS*
		development.
Reporting	The developers should prepare an EIA report containing a non-technical summary of the aforementioned information.	-
Review	The draft report should be submitted to the relevant authorities/ bodies for review. It should also be made available for review and comment by interested and affected parties and the general public. The comments should be fed back to the developers which should finalise the report in light of the comments received. The responsible authority should review the final documentation and make a decision in light of the report and consultation. Conditions may be attached to the approval e.g. relating to mitigation measures to be taken.	Currently authorities will find it difficult to review the EIA without EIA guidelines and acceptance criteria defined for CCS projects. This problem will also be exacerbated by the fact that there are few historical projects other than pilot studies and the Norwegian experience and that there have been no long term storage analogues to compare with. Studies are due to commence in the UK that involve the development of guidance for regulators to competently review CCS development applications. The role of the proposed expert panel in the review and institutional capacity building for review will address this issue.
Project Implementation and Operation	Developers should engage in monitoring and environmental management as per the plan. The aim of monitoring is to assess the effectiveness of the mitigation measures and to identify unforeseen effects. The responsible authority should ensure that any conditions attached to the approval are being met and that any required monitoring and reporting is reviewed.	Monitoring is discussed in Chapters 7 and 8. Post implementation monitoring and operation will fall into two phases. One is during filling of the reservoir and one is after closure of the reservoir, when monitoring will still be required. It has not been agreed how long monitoring will be necessary for and who will be responsible for it in the long term (see Chapter 8); this will need to be clarified. With regards to storage, the EIA will need to include commitments for post-closure monitoring, and provisions for handling long term liability.
Project decommissioning	A second EIA is required at this point to ensure that closure, decommissioning, infrastructure removal monitoring etc is done according to BAT at the time these operations cease. Part of this EIA is envisaged to be a declaration of state of reservoir and lateral migration and a prediction of what will happen in the future in terms of lateral migration. Financial provisioning for the long term monitoring and management.	Acceptance criteria for ownership transfer from operator to national authority needs to be determined. Financial mechanisms need to be defined along with provisioning arrangements. There are some drivers to suggest that this provisioning must be accumulated from CO_2 credit value during the operational phase of CCS.
Long term steward ship	Mechanism for future (1000 year plus) site identification and warning to exclude intrusion or damage to cap rock and long term monitoring and management.	Responsibility and mechanisms need to be defined.

7.0 Information Requirements for EIA & SEA: CO_2 Storage Reservoirs

7.1 Introduction

As identified in Chapter 6, it is considered that the information necessary to undertake an environmental assessment of the stage covering injection and storage of CO_2 in a CCS project is not well defined, and has many uncertainties associated with it. The uncertainty relates primarily to CO_2 lateral migration and leakages, whether from faults, well blow outs, cap leaks, poor injection etc. In many cases the likelihood of such leaks and their size is not well defined nor is it well understood how geological reservoirs will respond over the long time frames envisaged for these projects. Additionally, the effect of CO_2 leakages upon some sensitive receivers (e.g. marine ecosystems) is currently not well understood.

As CO_2 injection and storage is poorly defined in many respects, it is considered separately in more detail in this chapter, which examines the following issues:

- CO_2 release mechanisms
- Risks of CO_2 release during injection and storage
- CO_2 receptors
- Modelling release of CO_2
- Effect of CO_2 on Oceanic Ecology
- Onshore environmental effects of CO_2 exposure
- Impact of Impurities in CO_2
- Monitoring of CO_2 Storage Projects
- Remediation of Leaking CCS Projects

7.2 CO_2 Release Mechanisms

Table 7.1 below provides an overview of the main mechanisms that could lead to a material release of CO_2. These mechanisms are reviewed, with focus on their likelihood and the quantities of CO_2 which could be released and the implication this will have on the EA methodology that will be required. In practice, the likelihood of release and potential quantities will be site and practice dependant, so the discussion presented here is of a generic nature. The main source of evidence for this section is drawn from the IPPC report 2005 Chapter 5 (Coordinating authors Benson and Cooke), a major peer-reviewed status report on underground geological storage.

“No existing studies systematically estimate the probability and magnitude of release across a sample of credible geological storage systems” (IPCC 2005). However, evidence is available from five sources:

- Data from natural systems
- Data from engineering systems, such as EOR projects
- Understanding fundamental physical, chemical and mechanical processes
- Results from numerical models of CO_2 transport
- Results from current geological storage projects (IPPC 2005).

Obtaining useful leakage statistics from natural geological storage systems, with potentially historical engineered infrastructure in the system and for the likelihood for CO_2 leakage, is difficult. CO_2 leakage has never been a regulatory issue, and no accounting for leakages has been required historically.

The potential loss of CO_2 from any of the escape mechanisms presented in Table 7.1 could be reduced through appropriate monitoring and remedial actions. Any detection or indication of CO_2 release or CO_2 migration beyond expected boundaries can be followed by remedial actions to minimise the amount of CO_2 that may be lost. On this basis there is a balance between the costs of ensuring appropriate site selection and monitoring /remedial action needs. Typically, preventative planning is cheaper and more efficient, in terms of end result, than remedial activities. However, with the lack of knowledge on the long term behaviour of CCS reservoirs, a balance will need to be achieved using a reasonable risk approach with acceptance criteria.

The global impacts of CO_2 leakage will be substantially greater if multiple projects have CO_2 containment failures. Common failures could occur if there is a common misunderstanding about the risk of CO_2 leakage. When assessing the global environment impacts strategically, it is important to identify release mechanisms that could be common to projects. For example, if CO_2 releases occur as a result of general lack of knowledge about the properties of caprock, a situation could arise that a large number of projects leak CO_2 to the atmosphere. This suggests that the SEA's need to be reviewed at regular periods or after events occur and that the EA methodology and acceptance criteria will need to be reviewed as knowledge improves.

Multiple significant leakages in different reservoirs will in the short to medium term result in reputation damage, loss of confidence in the technology as well as potentially exacerbate CO_2 climate issues. The last point is a particular risk as CCS may allow, as a consequence of assumed abatement, for an increase in the production of CO_2. This is potentially possible if for example Europe stores CO_2 and China increases their use of fossil fuels. The net effect is that atmospheric CO_2 will increase more slowly, but if a European storage site fails, there will be a significantly larger pool of CO_2 available to enter the atmosphere. If there is a common failure mode that is inherent in many projects this situation could potentially have significant impact on the environment and human survival as we know it today. The SEA should therefore also consider the potential loss of containment from CCS projects in the face of increased CO_2 production and the implication thereof, as well as the need for hydrocarbon fuel or energy replacement as part of the same process. CCS is only seen as part of the overall solution to combating climate change, energy security and accumulation of GHG gases in the atmosphere. The role of the SEA in setting up a country focus to assess the overall energy and emission status needs to be considered.

Table 7.1 below provides an overview of the main mechanisms that could lead to a material release of CO_2. Section 7.3 provides an overview of the key risks detailed in the following table.

Table 7.1 - Release Mechanisms

Release mechanisms	Review discussion	Likelihood	Potential quantities	Assessment/ Knowledge gaps
WELL/ DRILLING MECHANISMS				
Leakage through active or abandoned wells	A number of leakage pathways exist that can combine in various ways and allow the migration of CO_2 upwards and to circumvent well plugs. Possible leakage pathways from mechanical failure and chemical influence have been identified as: • Between casing and plug (upwards) • Between casing and cement wall (upwards) • Through well plug (upwards) • Through casing • Through cement casing • Between the cement wall and rock (upwards) (IPPC, Benson and Cooke, 2005) Cap rock and reservoir characterisation exploration efforts during baseline studies and pre-injection reservoir site approval will need to be minimized because it is undesirable to pepper the ground with exploration wells while looking for suitable storage sites, as this can reduce the integrity of the potential sites. However, sites with no boreholes nearby must expect to drill several at least through the candidate storage reservoir. The key issue is to understand the condition of the wells and seal them appropriately; this will be difficult in many cases. In addition, well damage could also be caused by terrorist attack/ sabotage, tsunami/ tidal waves, earthquakes and tremors and collisions (such as from shipping and icebergs) and disturbance by trawling where fishing nets pull up sea floor infrastructure. Operators are normally required to report leaky well-bores that	Injection wells and abandoned wells have been identified as <u>one of the most probable leakage pathways in CO_2 storage projects.</u> (Gasda et al, 2004; (IPPC Benson and Cooke 2005). "The risks of leakage through abandoned wells is proportional to the number of wells intersected by the CO_2 plume, their depth and the abandonment method used "(IPPC, Benson and Cooke, 2005). Leakage due to corrosion of tubing can be managed by lining with polyethylene to reduce corrosion to <2.5 µm/pa.	Significant	There is a lack of knowledge about the risks of leakage from abandoned wells caused by material and cement degradation (IPPC, Benson and Cooke, 2005). This is due to the uncertainty on geological timescales over which wells will need to be effective. The EA should therefore include a record and profiling of all wells, historical and planned and these should be made part of the overall risk assessment. The characterisation of the reservoir for the EA and for the purpose of defining the boundaries of migration of the CO_2 should be done so as not to sterilise any potential reservoir by drilling unnecessary holes. A strong, clear regulatory regime is required to manage exploration of potential CCS sites; this currently does not exist. It will require effective tools, work processes and service providers to apply such a regime, and will need to allow for the practice to be heavily site dependent. The risk assessment should, in particular, be used on historical wells for which limited information is available about condition and capping methodology. In older exploration areas the threat of poorly sealed wells being encountered will be higher.

Release mechanisms	Review discussion	Likelihood	Potential quantities	Assessment/ Knowledge gaps
	emit methane through the annulus. The annulus is the gap between concentric pipes installed permanently in a well-bore that are ideally filled with cement. Due to various reasons, the cement does not always fully cover the annular space and therefore provides a potential leak path to the surface. Such methane and CO_2 leakage may in fact be a significant source of greenhouse gases in CO_2 EOR projects. In CCS projects the acidic constituents in CO_2 may destroy the cement and if associated with removal of oxidised material may significantly weaken systems leading to premature failure. Wells that transect known fault lines (active and inactive) should be considered through risk assessment to determine the increase in risk this poses.			
Well blow out	Well blow out events are typically caused by operator error. For example, well-blow out can be the result of poor well development or an underestimation of the pressure within the reservoir. Well-blow would result in the uncontrolled release of CO_2 until plugged.	There is, naturally, no existing data for the probability of a blowout from a CO_2 injection well. However, the SINTEF BLOWOUT database (Scandpower 2006) estimates a 1.8×10^{-5} probability per well year for a blowout from a gas injection well. This may be representative for a blowout from a CO_2 injection well, provided the same safety barriers apply for a CO_2 injection well regime. The probability for a well release (short period/low volume release) is 2.0×10^{-5} per well year.	Significant Well blow out could cause a release of 5-10% CO_2 storage.	Reservoir engineers need to confirm their confidence in utilising data from gas injection wells.

Release mechanisms	Review discussion	Likelihood	Potential quantities	Assessment/ Knowledge gaps
Failed injection as a result of well bore blockages	Hydrates and ice formations can form in well bores and may block the valves of injection equipment.	Low with preventative measures in place, which include constant CO_2 phase (control of temperature, pressure, moisture) to ensure CO_2 stays in super-critical phase to minimise hydrate and ice formation (DNV 2003).	Small	Reservoir engineers need to confirm their confidence in capability of preventative measures.
Future drilling breaks storage formation containment/ integrity	Future drilling into CO_2 reservoirs could occur if records of CO_2 storage are poor, incorrect or if CO_2 has migrated beyond expected reservoir boundaries. Drilling activities in or near to storage sites needs to be restricted severely if not prohibited. This essentially means storage sites will cause potential resource sterilisation. Once used for CCS projects it is unlikely that the reservoir space, the geological areas above and immediately adjacent to CCS reservoirs can be used again. This sterilisation will extend beyond the project boundaries to any area contiguous with the reservoir that may allow a leakage pathway to form. Reservoir and contiguous areas will need to be characterised to determine resource potential and value. This characterisation will typically require additional drilling so needs to be approached sensibly to minimise potential disruption of the cap rock or reservoir integrity. Each site will need to be characterised as there will be spatial differentiation in resources and each site will be different.	Very dependent on controls	Significant	The SEA needs to consider the site sterilisation extent that will occur to the anticipated footprint of the project and contiguous areas to ensure that no other potential resources will be sterilised or rendered unusable. The SEA should report any loss of potential resources. The EA needs to define the drilling prohibition areas to the full extent of areas contiguous with the reservoir and the reservoir itself. An evaluation should be presented as part of the EA which describes the resources of the area and what will be lost. The lower the resource value of the reservoir and contiguous area, the less likely there is to be future drilling and disruption of the reservoir integrity or seal.
CO_2 charged water removed from reservoir leading to possible loss of CO_2	CO_2 could escape by dissolving in the water that is removed	Unknown and reservoir and operating methodology dependent.	Small	Lack of knowledge and site specific, being dependent on each reservoir's character and operating methodology employed. The EA should assess the nature of any liquids/materials that will be produced during storage operations for pollution potential and CO_2 loss potential. If water is displaced by CO_2 in

Release mechanisms	Review discussion	Likelihood	Potential quantities	Assessment/ Knowledge gaps
				reservoirs allowing it to naturally migrate out of the reservoir then the exit point of the water should be sought to determine the impact. If the exit is near the reservoir boundary it is likely that with continued storage operations the water will become acidic.
Operator error during injection, or equipment failure	CO_2 releases can occur during injection as a result of operator error or equipment (e.g. compressor) failure, or (e.g.) via a spill point if the reservoir is overfilled (proper site characterisation and selection will reduce risk).	There are a number of operator error possibilities.	Small to high potential loss	Traditional risk assessment used on capture and transport phases could be applied to injection although the risks will be less well documented. Statoil operations, at for example Sleipner, could be used as a reasonable failure and operator data source. This component will relevant to the EA but will be too detailed for the SEA.
Unknown/ old historic exploration wells	CO_2 would escape if injected into a storage formation with existing holes, unplugged wells or partially plugged wells. Some onshore fields do not have complete records of past drilling, such as for some fields in Canada. Some early North Sea wells were not accurately logged in terms of position or plugging procedure or extent.	Region dependent and can be reduced by pre-injection surveys.	Significant	The regions that have unrecorded wells are generally known. These regions should generally be ranked high risk in the SEA process. If they are to be developed further as CCS reservoirs the EA will need to include detailed risk analysis of these wells and unless retrospective mapping and sealing is included as part of the development process the EA should exclude further development. A condition of EA should be to survey the entire reservoir footprint and contiguous areas for all wells. Authorisation should be dependant on risk assessment and retrospective action. CO_2 loss through old wells should result in immediate authorisation withdrawal until the holes are sealed.

Release mechanisms	Review discussion	Likelihood	Potential quantities	Assessment/ Knowledge gaps
RESERVOIR MECHANISMS				
Leakage through existing fault	CO_2 could escape if injected into a storage formation with an existing fault. Survey work used to guide site selection might miss a fracture or underestimate its size. Sites with faults that are physically continuous with the surface onshore or offshore may have a higher likelihood of leakage and should be considered as 'potentially not suitable for CO_2 storage'. If a site has a reservoir fault line that is not followed into the cap rock (i.e. the cap rock is not affected by the fault) the effect of pressurising the reservoir should be carefully evaluated to ensure that this will not cause damage to the cap rock seal. This item is dealt with in more detail below.	Likely	Significant	There is scope to improve fault detection and characterisation of leakage potential (IPPC, Benson and Cooke, 2005). The SEA should prioritise down areas with known faults or known to be seismically active even if on the scale of thousands of years. The EA should require evaluation of the cap rock response to reservoir pressurisation. The Authority should restrict use of sites with faults that are continuous to the surface and base their decision on risk assessment of cap rock response to faulted reservoirs.
Leakage through fault caused by seismic activity in response to CO_2 injection.	Leakage can occur through faults opened by injection-induced seismicity, causing damage to life, property and the environment directly though earthquakes. Induced seismic activity should also be considered for its impacts on transport pipelines and injection infrastructure and well bore integrity. If well bores transect fault lines these wells should be subjected to risk assessment to determine the increase in risk.	Probably very low, but this may depend on the site, e.g. there will be some sites where background stresses in the storage formation rocks may already be high and a small perturbation may release some significant amount of seismic energy. There have been no significant seismic effects attributed to CO_2-EOR (IPPC, Benson and Cooke, 2005).	Significant	Appropriate site surveys and risk assessments should be presented as part of the EA. The SEA will only be able to identify those areas that are likely to be susceptible and which will need to be clarified during site specific EIA. Monitoring for seismicity will need to be made part of the operational and long term monitoring plan. Authorities will need to ensure the risks are identified and that appropriate monitoring measures are in place. If there is a high risk of induced seismicity the affects on well bores will need to be determined.

Release mechanisms	Review discussion	Likelihood	Potential quantities	Assessment/ Knowledge gaps
Leakage through fault caused by natural seismic activity	Leakage can occur through faults opened by naturally occurring earthquakes or seismicity. The level of seismic activity in a region and the potential for inducing fracturing are both key to assessing the risks of release from fracturing. The natural seismic event frequency distribution is generally known. Any areas that are known to have any form of tremor, geyser or volcanic activity should be treated as thermally and seismically active.	Significant only in some regions.	Significant	Humans have only been collecting data on this for a very short period of time relative to the time scale of the history of natural tectonic activity. The SEA should avoid any areas that are seismically active, show historically repeating seismic events or have evidence of volcanic or thermal activity. The EA should require a risk assessment based on cyclic repetition rate of seismic activity and overall seismic activity of fault. Authorisation should be dependent on extremely low risk of seismic activity.
Leakage through gaps in cap rock	Leakage from the storage formation could occur if the cap rock is not continuous.	Could be high	Significant	There is a lack of knowledge about the temporal variability and spatial distribution of leaks that might arise from inadequate storage sites (IPPC, Benson and Cooke, 2005). Areas that are known to have structural issues and faulting associated with the rock should be prioritised down during the SEA. The EA should consider the risks associated with pressurisation of the storage reservoir, possible seismicity (natural and induced), the buoyancy of the CO_2 and any disruption well bores (proposed and historical) may cause to the integrity of the cap rock.

Release mechanisms	Review discussion	Likelihood	Potential quantities	Assessment/ Knowledge gaps
Leakage through cap rock damaged by pressure of injection	Leakage can occur if the caprock is damaged. If injection occurs too quickly, the increase in pressure can damage the caprock. At the time of drilling there is often uncertainty around the characteristics of the cap rock; injection is often made without first obtaining a sample of the caprock.	Location and operations dependant	Significant	The EA should investigate the issues around pressurisation of the reservoir and the integrity of the cap rock. If the reservoir is water filled, the option of draining water at a rate equal to injection should be considered to ensure reservoirs are not over-pressured and any forced migration of water does not open potential new paths for CO_2 leakage. The water drained out of the reservoirs should be covered by the risk assessment to ensure that no impacts are created by pumping and releasing this material or liquid.
Diffusion of CO_2 through cap rock and other layers	CO_2 can pass through the caprock when gas pressure exceeds capillary pressure. The CO_2 will be liberated potentially over wide areas in slow bubbling streams. This could potentially have a high impact on the marine or water environments and associated communities into which the CO_2 leaks due to the high acidification potential. In onshore situations this CO_2 leakage is likely to accumulate in low lying areas, depressions and structures such as basements below the ground. Due to the slow release rate over wide areas the potential for immediate detection would be low.	Location dependant – potential to be a major mechanism. Important as would be relatively difficult to detect.	Significant	The EA should consider the risks of this leakage as well as the potential impacts on the marine environment and communities. In onshore situations, health and safety risk assessments will be required.
Dissolution of cap rock.	The injected gas can react chemically with the cap rock. The resulting dissolution can lead to subsidence and potential CO_2 release.	Location and operations dependant	Significant	The SEA should identify areas that have cap rock (such as limestone) which would be highly susceptible to oxidation or dissolution. The EA should reveal the extent of the risk of cap rock oxidation and dissolution.

Release mechanisms	Review discussion	Likelihood	Potential quantities	Assessment/ Knowledge gaps
Dissolved CO_2 migrates laterally out of the storage formation	CO_2 leakage can occur through the migration of gas from the injection point to the edges of the reservoir. This escape mechanism does not involve CO_2 moving through the cap rock; rather it migrates laterally beneath it. Sites that have significant artesian activity or which have stacked aquifers with mobile water bodies would suggest areas that need to be avoided as they are likely to have clear channels for migration of the CO_2 to the surface of the formation. The buoyancy and the viscosity of the CO_2 should be carefully considered as it will be more mobile than water.	Location dependant – likely to be the most important mechanism for aquifers.	Significant	The SEA should identify aquifers that are freely communicating with the surface water bodies and these areas should be given low priority as potential CCS sites. This will be site specific and features may exist in aquifers that will trap the CO_2 even if these are freely communicating with the surface. The EA should evaluate the nature of the sites and the risk that CO_2 will migrate from the reservoir. The CO_2 is expected to go into solution with the formation water so its eventual release from the reservoir/aquifer should also be considered in the EA. The risk on the receiving environment should be evaluated and based on that, risks determined for possible future impacts.

7.3 Risk of CO_2 Release during Injection and Storage

This section provides an overview of the key risks related to CO_2 release during injection and storage (detail provided in Table 7.1).

7.3.1 Injection Phase

This phase has a relatively limited period of operation (approximately 50 years). DNV (2003) estimated the risk of release of significant CO_2 (based on experience with the oil and gas industry) to be 10^{-3} per reservoir per annum. Corrosion of injection equipment is one of the main reasons for leakage (because CO_2 dissolves in water to form carbonic acid); this would need remediation, and by using polyethylene it would be reduced to less than 2.5µm/pa. Experience from CCS trials is required to increase confidence in utilising data from oil and gas injection wells.

The table below summarises the key risks and remediation associated with injection.

Table 7.2: Risks and Remediation during Injection

Release	Remediation
Outer corrosion of casing and tubing (by CO_2 dissolved in water)	Tube lining with polyethylene; annulus between casing and tubing filled with inhibitor fluid; during shut-off filled with inhibitor
Inner corrosion of tubing (by moisture in CO_2)	Reduction of moisture content in CO_2 Reduction of H_2S, NOx and SOx in CO_2
Blocking of wellbore	Constant CO_2 phase (control of temperature, pressure, moisture content) to ensure that CO_2 stays in super-critical phase to minimise hydrate and ice formation (DNV 2003)

7.3.2 Post-injection phase – key risks

Possible CO2 escape pathways are:

- Abandoned wells/wellbore failure:
  For old oil and gas fields, the highest risk is likely to result from the presence of former wells with poor sealing, and sometimes their locations may not have been recorded. These releases could result in rapid and sudden release of CO_2, are likely to be detected quickly and can be contained using techniques that are available today. The provision of long term management capability is necessary to enable a fast response to minimise the volumes of CO_2 released. The overall amount of CO_2 leakage is likely to be small in relation to the total amount injected. The safety and health impacts associated with these releases are expected to be greatest.

- Diffusion flow through caprock (via faults, or by buoyancy through permeable zones): Caprock integrity is of the utmost importance to attain long term storage - and this detailed information may already be available from previous exploration studies. However, the effects of chemical interaction with the caprock are not well understood. Leakage if it occurs is likely to be more gradual and diffuse. The environmental impact of these releases is expected to be greatest.

- Dissolution and transport of CO_2 charged waters in the aquifer by groundwater flow is likely to be the most important leakage mechanism from aquifers.

In general, there is restricted available quantitative data on probabilities and amounts of leakage from CO_2 geological reservoirs. Risks will be heavily site specific, although Ecofys (2005) have compiled some limited quantitative data. Also, IPCC (2005) note that observations from engineered and natural analogues as well as models suggest that the fraction of CO_2 retained in *appropriately selected and managed geological reservoirs* is very likely to exceed 99% over 100 years and is likely to exceed 99% over 1,000 years.

The main difficulty for a quantified assessment of generic risks of CO_2 release from geological storage sites relates to:

- the lack of detailed long term monitoring of field trials or modelling done to date
- the conditions which determine the risks of release are extremely site specific (ECOFYS, Field 2005).

However, closely related industrial experience and scientific knowledge could serve as a basis for appropriate risk management, although the effectiveness of risk management methods needs to be demonstrated for use with CO_2 storage.

7.3.3 Characterising Reservoirs

Exploration efforts during baseline studies and pre-injection reservoir site approval will need to be minimised because it is undesirable to pepper the ground with exploration wells while looking for suitable storage sites, as this can reduce the integrity of the potential site. Conventional exploration often involves drilling numerous wells because they can be used later for production, and they also provide “well control” data which helps to build the subsurface model.

Ideal exploration methods for potential CCS sites would require:

- minimising the number of exploration wells, or
- wells which do not penetrate all the way through the caprock, or
- horizontal wells drilled from the side of the reservoir.

A site with no boreholes nearby must expect to drill at least several through the candidate storage reservoir. This should not be a problem, because oil and gas fields are being considered as potential storage sites and they often have tens to hundreds of old well bores. The key is to understand the condition of the wells and seal them appropriately; this will be difficult in many cases. A strong, clear regulatory regime must be in place with effective tools, work processes and service providers to apply such a regime; this does not currently exist. Such a regime will need to allow for the practice to be heavily site dependent.

Techniques developed for the exploration of oil and gas reservoirs, natural gas storage sites and liquid waste disposal sites are suitable for characterising CO_2 geological storage sites. Examples include seismic imaging, pumping tests for evaluating storage formations and seals, and cement integrity logs. Computer programmes that model underground CO_2 movement are used to support site characterisation and selection activities. These programmes were initially developed for applications such as oil and gas reservoir engineering and groundwater resources investigations. Although they include many of the physical, chemical and geomechanical processes needed to predict both short-term and long-term performance of

CO_2 storage, more experience is needed to establish confidence in their effectiveness in predicting long-term performance when adapted for CO_2 storage. Moreover, the availability of good site characterisation data is critical for the reliability of models (IPCC 2005).

Consequently, the implementation of more pilot and demonstration CCS storage projects in a range of geological, geographical and economic settings is important to improve our understanding of the risk issues.

7.3.4 Specific Technical Gaps in knowledge relating to Reservoir

The CO_2 storage site is the key area of risk, and the following areas are not currently well understood:

Mapping the Underground
The critical process for evaluating a potential reservoir site is comprehensive mapping of the reservoir and surrounding area, hence it is important that coverage achieves the necessary depth of data collection, resolution and clarity. There needs to be clear minimum standards for such data collection such that site developers will not compromise the storage integrity evaluation due to under-investing in data collection.

Identifying Discrete Potential Leak Paths in the Underground
The map of the underground should reveal all examples of two discrete types of potential leak paths, faults and “thief zones”. These features can in some cases be identified by visual inspection of seismic data, although this can be very time-consuming and subjective, so many suppliers of seismic processing software have developed automated algorithms that directly point to such features. These automated techniques have weaknesses; hence the process is a combination of human interpretation, software utility and application, and quality control. These challenges are site specific, and the permitting regime should be designed to anticipate and handle this.

Upscaling Fine Grid to Course Grid CO_2 Flow Simulators
An additional challenge is related to resolution of forward-looking simulation models of dynamic CO_2 flow in the underground and the ability to adequately represent fluid movement, dissolution and other physical processes which might otherwise be negligible over the time period of the life of an oil or gas field. The numerical resolution in such flow models (simulators) is limited by computer memory and computation time. It is essential these be calibrated properly against the true geological structure in a consistent and practical way, and that this modelling process is verifiable.

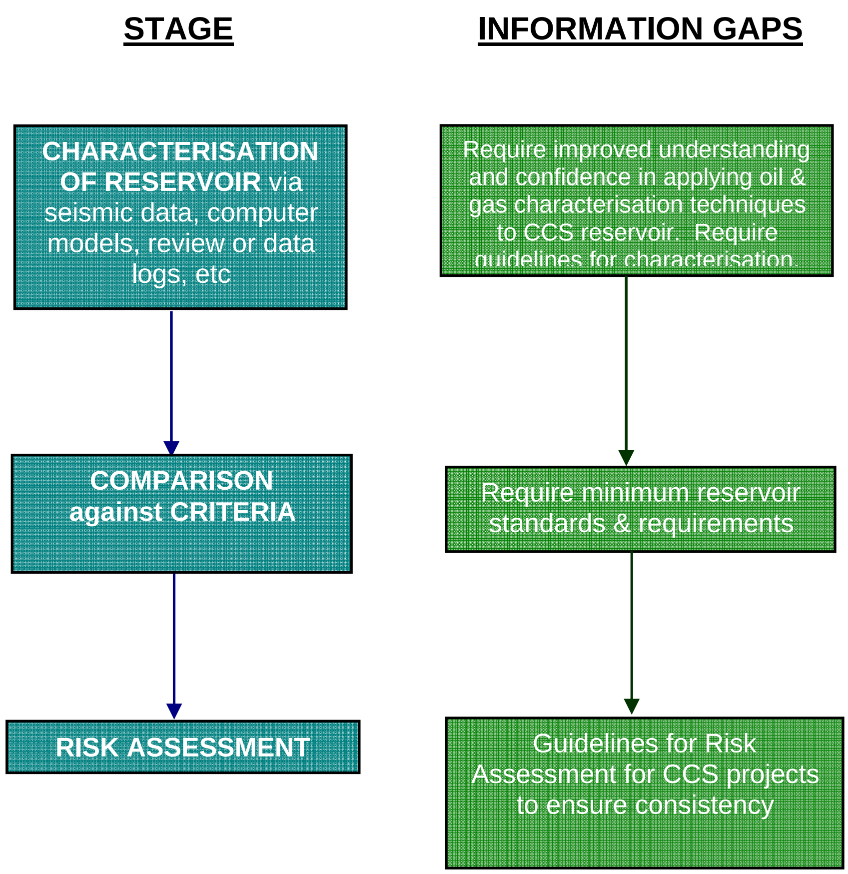
Modelling of Uncertainty in Leakage in the Underground
Traditional tools for modelling uncertainty may be insufficient when estimating probability of long-term leakage from CO_2 geological storage. Although research has been done in the area of uncertainty analysis of subsurface flows, many of the proposed methods are either of low applicability to actual field conditions, or computationally very intensive. For example, the classic Monte Carlo simulation method (MCS) is considered to be a very popular tool for the stochastic risk assessment procedure. MCS is a very general methodology, but its accuracy is low for combinations of small sample sizes and discrete events with small frequencies/probabilities, and it can become prohibitively expensive and time consuming.

7.3.5 Guidelines for Risk Assessment

There are currently no generic minimum site requirements or criteria for a CO_2 storage reservoir; and there are no guidelines available that provide a minimum methodology to quantify probability and quantity of release risk. It is recommended that an Expert Panel meet to produce such a document. To be able to produce a risk assessment of CO_2 release that is trusted and consistent, a systematic methodology is recommended; note that some work in this area has commenced in a current study (CO2STORE). It is recommended that the guidelines consider whether:

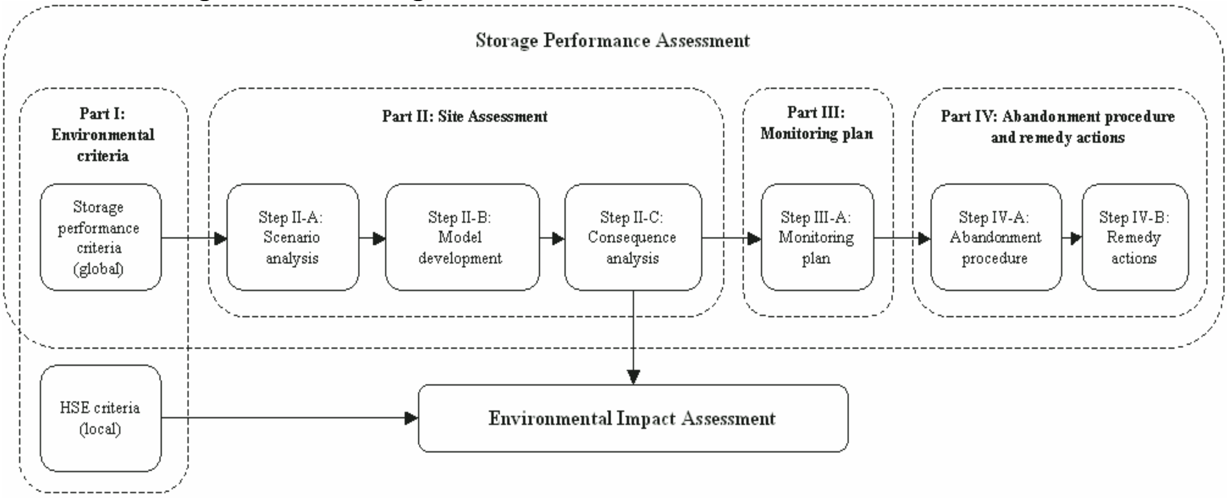
- minimum lateral distances of populated areas from reservoirs are advisable;
- the following types of areas should be screened out or have their priority for CCS development downgraded:
  - areas with endangered/threatened species of plants and animals, and sites that have a high conservation value
  - areas with low turnover lakes and lakes with sensitive or endangered communities
  - areas with significant sources of groundwater located nearby
  - areas containing many old or abandoned wells.

Figure 7.1: Key Stages of Reservoir Risk Assessment of CO_2 release & Knowledge Gaps



The risk assessment will need to incorporate the results of the Storage Performance Assessment (SPA) – a draft of such a scheme has been developed by Statoil and is characterised schematically below - as an inherent part of the EIA. It could be possible to set minimum requirements (via an expert panel) for best practice SPA in order to get a good practice EIA. This should include scenarios which assess the potential magnitude of seepage events along various potential pathways, and the subsequent receptors associated with such scenarios. As such, an implicit part of the EIA process will be characterisation, performance assessment and risk analysis.

Figure 7.2: Storage Performance Assessment



Source: Statoil

In summary, with regard to CO_2 storage in a reservoir, key research needs include assessing CO_2 properties and behaviour in geological formations, better understanding the impact of impurities and developing a suite of modelling techniques to predict the short and long term fate of stored CO_2 in a variety of geological formations (Natural Resources Canada 2006).

7.4 CO_2 Receptors

The scope of environmental assessments for CCS differs from normal EIA in terms of the long timescales required for CCS and that part of the receiving environment will be the geological and soil strata below the surface of the seabed or the onshore landscape. For example, microbes exist to considerable depths below the sea floor. The long time periods for storage and the novel receptors will pose challenges in the impact assessment process.

The approach to impact assessment should follow the *source-pathway-receptor* approach; this examines the following: a source of pollution, a pathway between the pollutant source and the receiving environment, and an environmental receptor who/which is susceptible. In order to realise an environmental impact all three parts of the impact chain need to occur. In CCS, the source will be CO_2 and any impurities that are in the gas stream, any products formed such as carbonic acid when CO_2 comes into contact with water, the pathway to a large extent has been dealt with in the section above and reflects the leakage paths the CO_2 will follow. The last part of this is now the receiving environment or receptor. The various receiving environments or receptors that could potentially be impacted are considered in this Table 7.3 below, and subsequent sections 7.5, 7.6, 7.7, 7.8 provide an overview of the key risks.

MANAGING RISK

Table 7.3 - CO_2 Receptors

CO_2 Receptor:	Comments	Importance	Assessment/ Knowledge gaps
ONSHORE SINKS			
Atmosphere	Any leakage to the atmosphere will contribute to the Enhanced Greenhouse Gas Effect. By continuing to increase CO_2 levels there are fears that positive ocean atmosphere feedback cycles will be activated and that runaway warming could result. The mechanisms for this are speculative but they are not yet well enough understood to fully understand the exact implications of not controlling atmospheric CO_2 concentrations. This creates a need for CCS which is currently the only large scale technique for controlling and possibly reducing CO_2 emissions.	If CO_2 production continues or increases as is expected with the industrialisation of areas such as China and if leakage occurs as a result of an issue shared by a large proportion of CCS projects, the impact in terms of climate change could be catastrophic. It is however unlikely that many CCS reservoirs will leak significantly nor fail on a large scale, provided effective controls are implemented.	The Enhanced Greenhouse Gas Effect is a major research topic. This research however will be more focussed on what will happen if CO_2 and other green house gases are not controlled and if anything will only reaffirm why CCS type techniques are required. The SEA will need to determine the extent of the potential CCS reservoir capacity. The EIA will need a thorough risk assessment of the proposed reservoirs for leak potential to determine if the risk to atmosphere and project is acceptable.
Agricultural land	If CO_2 escapes through agricultural land, the overall impact will generally be negative. "While elevated CO_2 concentrations in ambient air can accelerate plant growth, such fertilization will generally be overwhelmed by the detrimental effects of elevated CO_2 in soils, because if CO_2 fluxes are large enough to significantly increase concentrations in free air they will typically be associated with higher CO_2 concentrations in soil" (IPPC, Benson and Cooke, 2005). This will essentially turn the soil into an anaerobic environment which will disrupt the ecosystem in the soil significantly reducing its biotic carrying capacity. The increase in CO_2 in the moist soil environment will also increase the acidity of the soil leading to alterations in the communities that soil can support.	Leaking CO_2 could reduce the productivity for the duration of the leakage. The worst case, the CO_2 could sterilise the soil for the duration of the leakage. These impacts, however, are reversible. Soil acidity changes would take longer to reverse and could potentially add significant costs to CCS projects.	Some knowledge is available, although further research studies are on-going and are necessary (see Section 7.7.3). Adequate monitoring systems will need to be in place and monitoring regimes created that will address the concerns of farmers and surrounding communities. The EA will need to assess these risks.

CO_2 Receptor:	Comments	Importance	Assessment/ Knowledge gaps
	"CO_2 concentrations above 5% may be dangerous for vegetation and as concentrations approach 20%, CO_2 becomes phytotoxic" (IPPC, Benson and Cooke, 2005). Also, practical studies are on-going at Nottingham University (UK) that consider the effect of CO_2 upon vegetation (see 7.7.3).		Agricultural areas would have a higher priority as CCS development zones than populated areas.
Vadose zone (zone of earth between the land surface and the water table).	For onshore storage sites, CO_2 that has leaked may reach the water table and migrate into the overlying vadose zone. This occurrence would likely include CO_2 contact with drinking water aquifers. Depending on the mineral composition of the rock matrix within the groundwater aquifer or vadose zone, the reaction of CO_2 with the rock matrix could release contaminants (IPPC Benson and Cooke 2005). Acidification of the water could lead to the solubilisation of metals which could render drinking water harmful. Leakage into the Vadose zone will displace soil gas as CO_2 is approximately 50% denser than air. CO_2 leakages can poison the root systems of trees and plants thereby killing them.	Important	Seepage of CO_2 is common in regions influenced by volcanism. Naturally occurring releases of CO_2 provide a basis for understanding the transport of CO_2 from the vadose zone to the atmosphere, as well as providing empirical data that link CO_2 fluxes into the shallow subsurface with CO_2 concentrations in the ambient air – and consequent HSE risks. Such seeps do not, however, provide a useful basis for estimating the spatial and temporal distribution of CO_2 fluxes leaking from a deep storage site, because (in general) the seeps occur in highly fractured volcanic zones, unlike the interiors of stable sedimentary basins, the likely locations for CO_2 storage (IPCC 2005)
Populated areas	Leakage of CO_2 during periods of low wind can allow pooling of CO_2 at concentrations that are toxic for life (animal, plant and human). Normally human fatalities can occur at CO_2 concentrations of 7-10% (DNV 2003) and potentially lower concentrations if the weakest susceptible individual in a population is used as the indicator receptor. Sources of risk for this type of leakage event are dominated by surface facilities, i.e. at the well head of CO_2 injection wells and pipeline distribution networks. In onshore CCS projects leakages from reservoirs could affect the basements of buildings etc. Note also that induced seismic activity could potentially cause damage to structures and buildings.	Human fatalities are unlikely, although if an injection was made under a large city, this may not be the case due to high population densities. These problems can be exacerbated as cities tend to have lower wind speeds due to the complex terrain suggesting that the CO_2 will not be as effectively dispersed if reservoir leaks were to occur. Note that impaired function owing to CO_2 exposure should also be considered.	If there are many subsurface human facilities in an area where there is a risk of leakage, remedial measures will need to be advised such as forced ventilation. Monitoring in these areas will need to be come part of the authorisation and needs to be covered in the EA. SEA should generally give a lower CCS development priority to heavily populated areas with high levels of subsurface infrastructure and structures. Guidance may be advisable for minimum lateral distances of populated areas from reservoirs.

CO_2 Receptor:	Comments	Importance	Assessment/ Knowledge gaps
Habitats	As stated for agricultural land, "CO_2 concentrations above 5% may be dangerous for vegetation and as concentrations approach 20%, CO_2 becomes phytotoxic". Ground-dwelling animals are more likely to be affected by exposure than are humans (Oldenburg and Unger, 2004). Burrowing animals are most likely to be affected as the CO_2 is likely to accumulate in the burrows as it is generally heavier than air mix. An example of vegetation being impacted occurred at Mammoth Mountain, USA, in 1989, where pine trees over an area of 40 ha died (Rogie et al, 2001).	Leakage could cause vegetation to die-off and impact ground-dwelling animals, with knock-on effects in the food chains. If species are removed from the ecosystem, the impacts might be irreversible. There is no evidence of terrestrial impact from current CO_2 storage projects (IPPC, Benson and Cooke, 2005).	Areas with an endangered or threatened species of plants, animals or sites that have a high conservation value will need to be screened out during the SEA. The EA for a potential CCS project will require a listing of species, populations and ecosystems/environments at risk and be supported with a risk assessment of the CO_2 leakage threat.
Caves and indoor environments (i.e. basements)	Escaping CO_2 could collect to dangerous levels in caves and indoor environments, particularly basements. The CO_2 is likely to accumulate in basements and caves as it is generally heavier than air mix and these structures frequently do not have good natural ventilation.	Could result in fatalities.	Discussed in more detail in the "populated areas" section.
Lakes with seasonal turnover of water	Lakes in seasonal regions, such as Europe, have a greater rotation of water than lakes in regions without marked seasons. This turnover prevents gas being leaked into the lake and collecting at the bottom eventually building up to a level that could cause a sudden and high-concentration release. CO_2 levels building up in the lake waters could cause an anaerobic environment or an oxygen depleted environment to be created which may lead to alterations in the community composition of the lakes. CO_2 could also dissolve into and lower the pH of a water body. This could cause metals (ions) to go into solution and contaminate the water body.	The risk of contamination is important. The risk of rapid depressurisation and release of CO_2 is unlikely, due to seasonal rotation.	The SEA needs to identify areas that have low turnover lakes and lakes with sensitive or endangered communities, and downgrade their priority for development. May be advisable to have minimum requirements in guidance. The EA will need to determine the risk of ions going into solution and the threat this poses to lake biotic communities. The risk of accumulation of CO_2 will also need to be evaluated during the EA. The EA should also contain information on monitoring of the lake for pH and CO_2 concentration as well as potential monitoring that may be required to evaluate the species composition of fresh water bodies.

CO_2 Receptor:	Comments	Importance	Assessment/ Knowledge gaps
Lakes in regions that are not strongly seasonal	Lakes in regions without much seasonality have relatively less rotation of waters, such that the concentration of CO_2 can build up within stratified water columns. A sudden overturn caused by a natural or anthropogenic disturbance, could result in the rapid depressurisation and large scale release of CO_2. Only three lakes in the world are known to naturally contain high concentrations of dissolved CO_2 in their bottom waters. These are Lake Kivu in East Africa, and Lakes Nyos and Monoun in Cameroon. The release of large quantities of CO_2 from lakes is very rare; however, massive CO_2 releases from Lake Nyos in 1986 caused at least 1,700 fatalities. If CO_2 release from a sudden turnover is deemed a risk, pipes can be installed to mix the water layers and prevent any build up of CO_2.	A sudden release of CO_2 from a lake could result in multiple fatalities, although this risk once identified is manageable. .	The SEA should identify bodies with low turn over rates and down prioritise these. The EA will need to determine the risk of ions going into solution and the threat this poses to lake biotic communities. The risk of accumulation of CO_2 will also need to be evaluated during the EA. The EA should also contain information on monitoring of the lake for pH and CO_2 concentration as well as potential monitoring that may be required to evaluate the species composition of fresh water bodies.
Rivers/ Streams	The turbulence from even the slowest moving river will release CO_2 back to atmosphere. Rivers that are sourced underground could be acidified, which would reduce river biodiversity.	The potential for leakage of CO_2 into running water is not seen as an important risk.	The EA should require the acidification of the water to be assessed as part of the monitoring programme to ensure that biodiversity is not negatively impacted.
Groundwater	CO_2 lowers the pH in underground sources of drinking water which can mobilise metals that are otherwise harmlessly bound in minerals in the aquifer reservoir rock. The mobilised minerals would contaminate the drinking water. During a trial injection of CO_2 in a deep saline aquifer in the US Gulf Coast, monitoring showed that injection increased groundwater acidity and concentrations of bicarbonate, iron, calcium, and other metals. The study concluded that the acidified groundwater was dissolving minerals, which could create pathways in the rock strata for gas or brine to escape (Kharaka et al 2006)	Leakage of CO_2 could make groundwater undrinkable due to acidification or metal mobilisation and contamination.	The SEA should down prioritise areas for CCS development if significant sources of groundwater are located near the potential CCS reservoir site. The EA will require adequate monitoring for groundwater contamination to be in place both for acidity and metal contamination.

CO_2 Receptor:	Comments	Importance	Assessment/ Knowledge gaps
OFFSHORE SINKS			
Ocean	At a global level, increased atmospheric CO_2 as a result of the combined leakage from CCS projects and CO_2 emissions from all sources such as vehicles and hydrocarbon based power stations, would increase the acidity of ocean water and particularly ocean surface waters. Coral reefs, calcareous plankton and other organisms whose skeletons or shells contain calcium carbonate may be particularly affected as the increase in acidity would weaken these structures. Most biotic species reside near the ocean surface, where the greatest pH change would be expected to occur, however, deep-ocean biota may be more sensitive to pH changes (Caldeira and Wickett, 2002). If there was an increase in the acidity of the oceans surface waters, the consequence would be a dramatic decrease in production of biological material at the planktonic level of the marine food chain. This could lead to catastrophic effects on entire ecosystems in large parts of the ocean as many other species higher in the food chain are dependent directly or indirectly on this plankton. At water depths less than about 2500 metres, CO_2 that seeps through the sea floor is less dense than sea water and will probably disperse very rapidly. If water depths are large enough or in the case that currents enhance mixing to a sufficient degree, then CO_2 could dissolve before reaching the atmosphere. The toxicity consequences of this are probably negligible, though this requires confirmation. Some of the CO_2 that seeps through to the sea floor will ultimately reach the atmosphere, but depending on the size of the seep, water depth and degree of mixing, this may take years or longer. At depths below about 2500 metres, CO_2 becomes denser than seawater and pools on the sea floor and is known to be toxic for marine life that rests on the sea floor.	Important If CO_2 was released from CCS reservoirs en mass, atmospheric concentrations of CO_2 could rise rapidly and ocean acidification would increase dramatically. With a rapid increase in atmospheric CO_2 concentrations and ocean acidity it is unlikely that biological systems will be able to adapt rapidly enough which could lead to extinctions or significant population declines. This then becomes a cost benefit analysis as CCS will reduce global ocean acidification, but if storage reservoirs leak they can cause local acidification from slow releases over a wide area or global acidification if there is a mass release of CO_2. So CCS will reduce the ocean acidification that is forecast to occur but the CCS reservoirs will need to minimise leakage to avoid local impacts.	The response of the oceans and marine species to increasing CO_2 concentrations is currently being researched; current understanding is limited. Of particular importance to CCS projects will be how the ecosystem responds and not just how individuals in the ecosystem respond. See Section 7.6. The SEA should screen areas that provide habitats for endangered or sensitive species which will be affected by changes to the overall community structure or the physical environment. The EIA should review the species composition and identify any interference that could occur on the sea floor in particular. The global ocean acidification offset of a single project should be weighed up against the potential impact a leaking CCS project could have on local biotic communities.

CO_2 Receptor:	Comments	Importance	Assessment/ Knowledge gaps
Deep sub-surface microbes (note relevant for onshore also)	Microbes are present at the deepest levels studied (up to almost 2.8km below seafloor). Microbes will probably exist even deeper where the temperature is tolerable (around 110 °C or less). These depths are not covered for the majority of other types of projects that warrant an EIA The state of knowledge around these microbes is poor as is knowledge of their distribution and how the overall microbial communities are interlinked at different depths. Certain microbes found in the seabed are protected, thus there is need to mention them in the guidance attached to the new EIA methodology. Note that a protected habitat species exists offshore in “pockmarks”. Fine-grained sediment in (e.g.) central North Sea are characterised by scattered shallow ovoid depressions in the seabed, called pockmarks. Pockmarks are probably formed by the escape of gas (primarily methane c.95%) into the water column leading to soft, fine-grained sediments being lifted into suspension and deposited away from the source. Active pockmarks (as opposed to ‘relic’ pockmarks) are associated with current and ongoing fluid / gas escape characteristics. These are of special concern because they can accommodate distinctive biota species usually associated with high concentrations of sulphide. Pockmarks are considered to be protected habitats and if identified can result in operators having to alter pipeline routes, drilling locations etc.	Knowledge limited	There is a lack of knowledge about the impacts on microbes in the deep subsurface (IPPC Benson and Cooke 2005). It is unclear what importance stakeholders and society in general would place on microbes in the deep subsurface, and what emphasis should be placed on the impacts on microbes.
Benthic sediments	Organisms live in, on top and just above the marine sediment. As a result, the Benthic sediment is critical for the food chains of the Benthic zone (lowest level of a body of water) of oceans and lakes.	Important	There is a lack of knowledge about the environmental impact of CO_2 on the marine seafloor (IPPC, Benson and Cooke, 2005). See section 7.6

7.5 Modelling release of CO_2 to the Marine Environment

Plymouth Marine Laboratories (PML) are developing a model to investigate CO_2 leaks to the marine environment, based on the European Regional Seas Ecosystem Model (ERSEM) which is currently being used to assess the impact of atmospheric CO_2 concentrations upon the marine environment.

The model will examine the CO_2 dispersal and environmental impact of different quantities of CO_2 leaks over different time periods from CO_2 storage reservoirs (both diffuse and point sources) to the marine environment under different scenarios, such as winter, summer, stratified conditions (remains within sea), non-stratified (CO_2 leak moves up to ocean surface).

The modelling will not investigate likelihood of release.

The modelling will continue through to 2008; PML will be running a modelling acidification impacts workshop in 2007 to bring modellers and researchers together to discuss future research strategies.

Gaps in knowledge include how a catastrophic release translates into CO_2 retained (dissolved in the marine system) i.e. how much CO_2, if released, would simply jet up through the water column and away to atmosphere.

7.6 Effect of CO_2 Leaks on Marine Environment

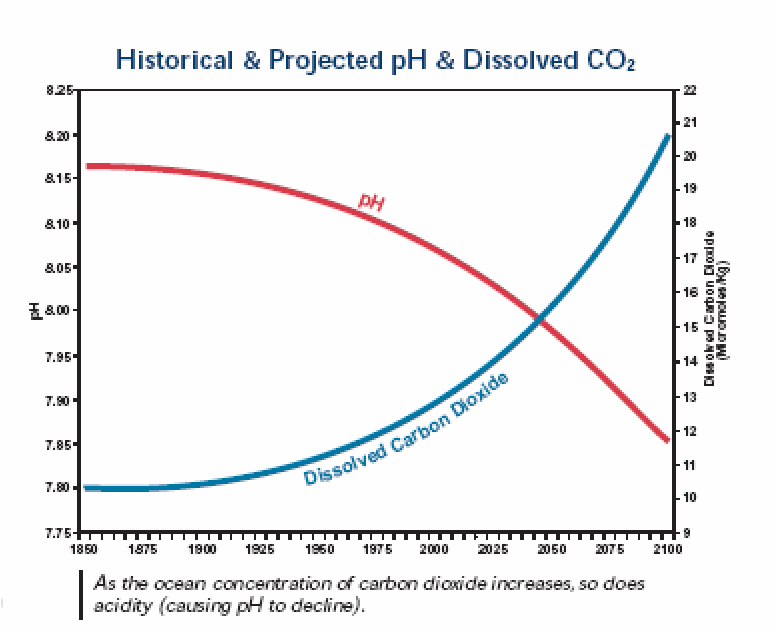
This section provides more detail regarding the environmental issues that can be expected as a result of a CO_2 release to the marine environment. Much of the knowledge gained to date derives from research studies that have investigated the impact of ocean acidification resulting from atmospheric CO_2 being absorbed by sea water.

7.6.1 Background & Ocean Acidification

CO_2 plays an important role in defining the pH of water. When CO_2 dissolves in seawater it forms a weak acid called carbonic acid (IEA 2002; Johnston et al 2002; Royal Society 2005). Part of the acidity is neutralised by the buffering effect of seawater, but the overall impact is to increase the acidity (lower the pH) of the water.

The oceans have absorbed nearly a half of all fossil-fuel carbon released into the atmosphere since the beginning of the industrial revolution, and they continue to soak up more. Previously, it was thought that the ocean's natural buffering capacity was capable of preventing any increases in acidity even with the large increases in CO_2 levels. But the speed with which CO_2 levels are now rising are overwhelming the ocean's natural buffering capacity, and are resulting in "ocean acidification" (New Scientist 2006).

The average pH of the oceans has already reduced by approximately 0.1 pH units compared against pre-industrial levels (see Figure 7.3), which, bearing in mind the pH scale is logarithmic, represents a 30% increase in the concentration of hydrogen ions (Turley 2006). pH has been relatively stable for over 20 million years



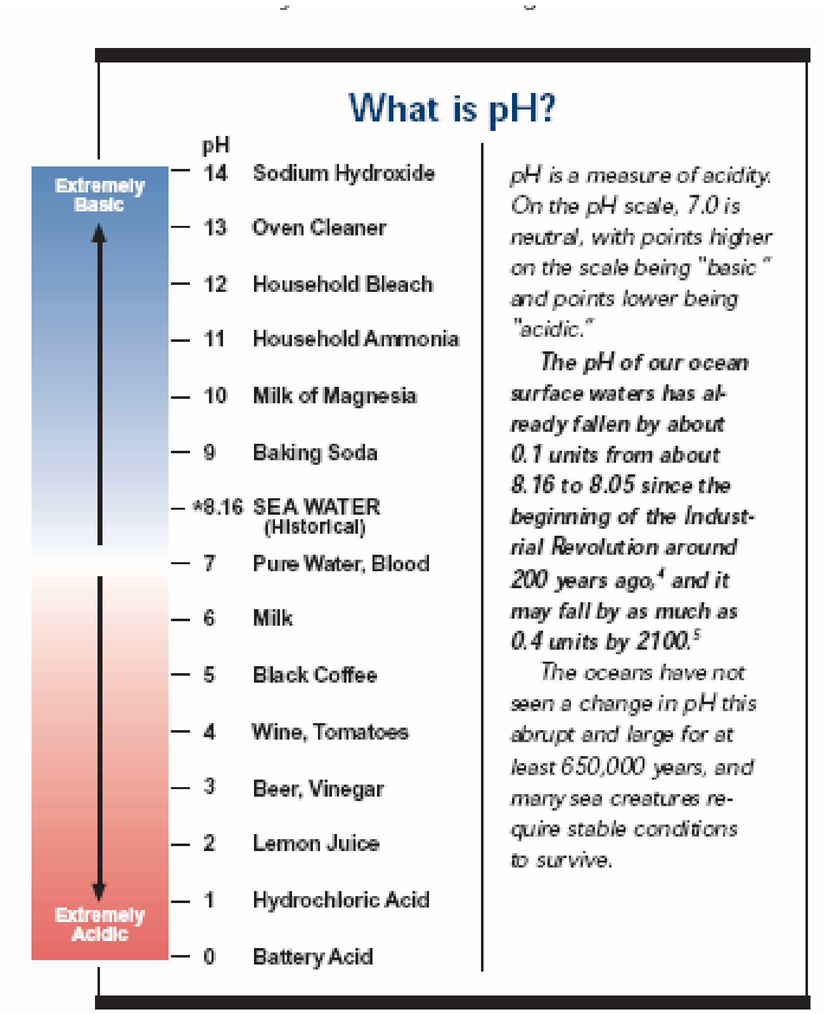


Figure 7.3: Relationship between Ocean CO_2 Concentrations & pH
(*Source: Feely, Sabine,& Fabry; http://www.net.org/documents/ocean_acidification_4-5-06.pdf*)

Calcareous (shelled) organisms are common in the sea (e.g. warm and cold water corals, some plankton, shellfish and sea urchins) and there is increasing evidence indicating that their ability to produce their shells will be reduced by 2050 as a result of ocean acidification (Turley 2006). Research shows that marine organisms and marine ecosystems can be detrimentally affected by ocean acidification.

The Royal Society (2005) produced a comprehensive report on ocean acidification in 2005 that concluded that acidification is inevitable without drastic cuts in CO_2 emissions. Although the report highlighted there is a great deal of uncertainty about the effects on marine life, there is no doubt that current knowledge shows that any significant CO_2 leaks from a CCS reservoir could have a significant impact upon marine organisms surrounding the leak.

7.6.2 CCS Leakage

Whilst growth in atmospheric CO_2 concentrations is expected to increase the acidity of the oceans, the plans to store CO_2 captured from large point sources in geological formations below the ocean has the potential to play an integral part in acidification of the oceans if leakages were to occur. If a storage reservoir(s) were to suffer a catastrophic failure releasing large quantities of CO_2 and various contaminants (e.g. H_2S) into the oceans and the atmosphere, the CO_2 concentration would increase in the atmosphere and water and this would affect the ocean pH. In an alternate scenario, if a large area was affected by slow bubbling releases of CO_2, the pH of the oceans would be directly impacted locally as a large amount of the CO_2 would dissolve into the sea water.

Changes in ocean chemistry, in particular acidification, could have substantial direct and indirect effects on ocean dwelling organisms and that the habitats in which they live, e.g. de-calcification and changes in the availability of nutrients (Royal Society 2005, DNM 2006, Greenpeace), as discussed in more detail below.

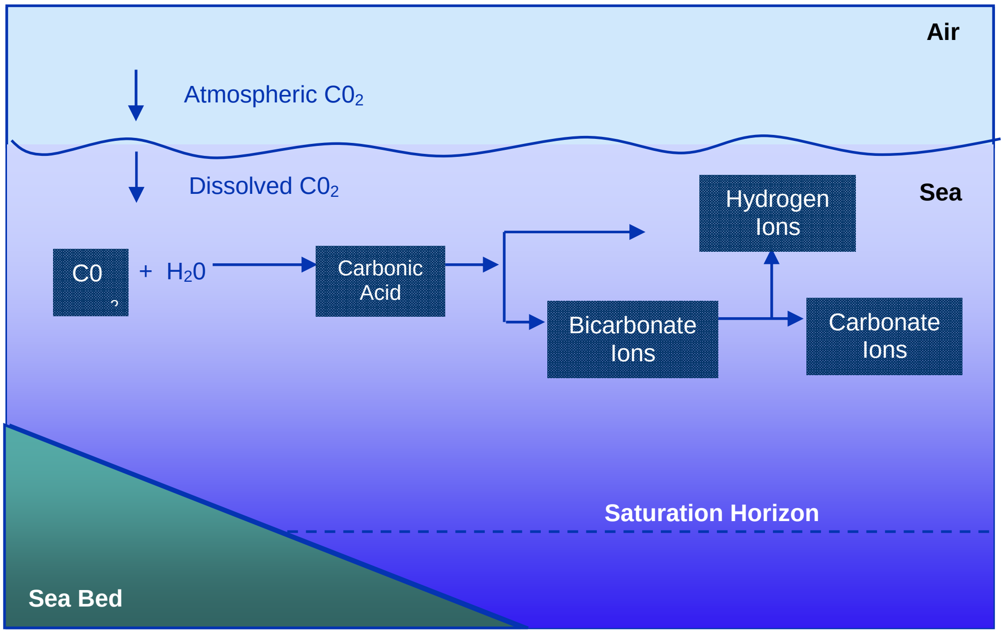
7.6.3 Effect on Oceanic Ecosystems

As indicated above, there are gaps in knowledge regarding the effects of CO_2 release on oceanic ecosystems because this area of research is relatively new. This section summarises knowledge to date.

Effect on small Calcium Carbonate ($CaCO_3$) Reliant Organisms

Marine organisms that construct $CaCO_3$ based shells require the presence of bicarbonate and carbonate forms of dissolved inorganic carbon in the seawater (Johnston et al 2002; American Meteorological Society 2005; Orr et al 2005; Royal Society 2005; DNM 2006; Feely 2006). Once formed $CaCO_3$ will dissolve back into the seawater unless it contains sufficiently high concentrations of carbonate ions. The oceans contain a natural boundary above which $CaCO_3$ can form but below which it dissolves (Royal Society 2005). Consequently the marine organisms that produce $CaCO_3$ based shells live above the saturation horizon where it does not dissolve easily. A significant release of CO_2 could have a potentially catastrophic effect on such organisms because increasing CO_2 levels and the resulting decrease in pH level of the water would decrease the saturation state of $CaCO_3$ and raise the saturation horizon closer to the oceans surface (Royal Society 2005).

Figure 7.4: $CaCO_3$ Saturation horizon



Source: Reconfigured from Doney, Scientific American, March 2006

Effect on Benthic Fauna

Corals, Crustaceans, Molluscs and Echinoderms are important benthic fauna and play a significant part in pelagic (middle depth) marine communities. Echinoderms are likely to be one of the groups most sensitive to ocean acidification (Royal Society 2005). During the larval stages of molluscs and sea urchins, magnesium bearing calcite is used to form parts of their skeletal structure. If the pH of seawater were to decrease it could potentially inhibit the formation of the calcite material needed for the construction of shells. The Royal Society also predicts that crustaceans are likely to be affected because of their need for calcium and bicarbonate ions to mineralise their exoskeleton after moulting.

Effect on Multi- cellular organisms & fish

Royal Society (2005) and DNM (2006) indicates that a decrease in pH and increase in CO_2 could potentially have a major effect on the marine multi-cellular organisms, predicting the following potential consequences:

- *"Hypercapnia"***-** Acidification of the tissues and fluids which affect the ability of the blood to carry oxygen; hypercapnia can occur in a matter of hours (Royal Society).
- Disturbances in breathing
- Narcosis
- Disturbances in reproduction
- Death
- Change in ability to function as intended (e.g. the ability of Cephalopods such as squid to move around the ocean could be compromised by acidification because the jet propulsion method of movement associated with cephalopods requires a good supply of oxygenated blood. This is likely to be compromised by increasing concentrations of CO_2 as it reduces the pH of the blood thus impairing the ability of the blood to carry oxygen).

- Disturbance in availability of organic carbon for deep ocean dwelling organisms (e.g. changes in the ability of calcified organisms to survive or function properly as a result of acidification would have significant implications for how the ecosystem functions. The pelagic ecosystem supplies the organic carbon that is used by organisms that dwell deeper in the oceans).

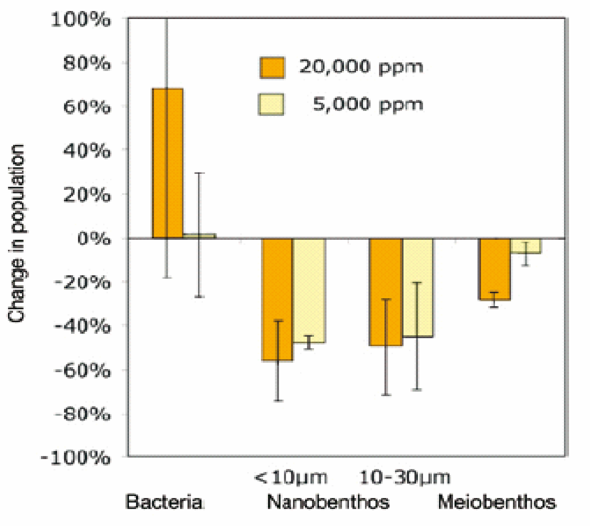
Effect on Sediment Dwelling and Benthic (bottom dwelling) Organisms

Sediment-dominated habitats, which occupy a large fraction of the area of the oceans, play a crucial role in several key ecosystem functions and processes in shelf sea environments. For example, in shallow (less than 50 m) coastal areas, productivity in the overlying water column relies on the sediment system, with up to 80% of the nitrogen required by phytoplankton coming from the bacterial regeneration of organic matter within the seabed (Dale & Prego 2002 *cited by Royal Society report*). Phytoplankton are the main marine primary producers upon which the whole marine food chain depends, so the supply of nutrients for their growth from the sediment is essential for sea shelf productivity.

Effect on Bacteria, Nanobenthos and Meiobenthos

Significant impacts of elevated CO_2 on meiobenthic organisms could not be found although in controlled experiments (IPPC 2005) where the impact of 5,000 and 20,000ppm rises in pCO_2 (with resulting pHs of 6.8 and 6.3) on the abundance and diversity of bacteria and of small animals (nano and meiobenthos) was analysed, it was noted that the abundance of *foraminifera* decreased significantly within 3 days at 20,000ppm. Also, the abundance of nanobenthos decreased significantly in most cases, whereas the abundance of bacteria increased at 20,000ppm (see Figure 7.5 below). It should be noted that such high concentrations would result locally from (e.g.) a CO_2 release but not from ocean acidification resulting from absorbtion of atmospheric CO_2.

Figure 7.5: Preliminary investigations of changes in bacteria, nanobenthos & meiobenthos abundance after exposure to 20,000 & 5,000ppm CO_2 for 77-375 hr during 3 experiments carried out at 2,000m depth in Nankai Trough, north-western Pacific; error bars represent 1SD



Source: Intergovernmental Panel on Climate Change 2005

To summarise, there is little data on the impacts of low pH/high CO_2 on elements of marine bacteria and phytoplankton. There is an urgent need to invest in understanding the impacts of

CO_2 levels on these fundamental elements of the marine food chain (both phytoplankton and bacteria are major drivers of ocean productivity and the oceanic carbon cycle).

General effects

At the ecosystem level, few studies carried out in surface oceans report that species may benefit under elevated CO_2 levels. Species that are less sensitive to added CO_2 could become dominant in a high CO_2 environment, in this case due to stimulation of photosynthesis in resource limited phytoplankton species. These conclusions have limited applicability to the deep sea, where animals and bacteria dominate. In animals, most processes are expected to be depressed by high CO_2 and low pH levels, see Table 7.4 below, Note that some of the impacts detailed could only result locally from (e.g.) a high CO_2 release from CCS, and not from ocean acidification resulting from absorbtion of atmospheric CO_2.

Table 7.4:Physiological & ecological processes affected by CO_2 (note: listed effects on phyto-plankton are not relevant in deep sea, but may become operative during large-scale mixing of CO_2)
Based on review by Heisler 1986, Wheatly & Henry 1992, Claiborne et al 2002, Langdon et al 2003, Shirayama 2002, Kurihara et al 2004, Ishimatsu et al 2004, 2005, Pörtner et al 2004, 2005, Riebesell 2004, Feeley et al 2004 & refs therein (IPPC 2005)

Affected processes	Organisms tested
Calcification	• Corals • Calcareous benthos and plankton
Acid-base regulation	• Fish • Sipunculids • Crustaceans
Mortality	• Scallops • Fish • Copepods • Echinoderms/gastropods • Sipunculids
N-metabolism	• Sipunculids
Protein biosynthesis	• Fish • Sipunculids • Crustaceans
Ion homeostasis	• Fish, crustaceans • Sipunculids
Growth	• Crustaceans • Scallops • Mussels • Fish • Echinoderms/gastropods
Reproductive performance	• Echinoderms • Fish • Copepods
Cardio-respiratory functions	• Fish
Photosynthesis	• Phytoplankton
Growth and calcification	
Ecosystem structure	
Feedback on biogeo-chemical cycles (elemental stoichiometry C: N:P, DOC exudation)	

Source: Intergovernmental Panel on Climate Change 2005

7.6.4 Mitigation of ocean acidification

Royal Society (2005) and Caldeira et al (2005) suggest that the effects of CO_2 acidification could be counteracted to some extent if enough of an alkaline substance were added to the ocean to restore the carbonate saturation levels. But the report suggests that only half of the pH change would be mitigated. The effect of trying to restore the pH of the ocean is that it would become oversaturated with carbonate minerals which in itself could have implications for the ecosystem. Research cited by the Royal Society suggests that soluble minerals such as magnesium hydroxide could work, although such minerals are expensive, rare and unlikely to available in the necessary quantities.

There is a high degree of confidence that reducing CO_2 emissions to the atmosphere is the only way of reducing ocean acidification (Turley 2006).

7.6.5 Current Research

In relation to the identification of thresholds of CO_2 in water above which high levels of mortality would occur, Monterey Bay Research Institute MBARI (personal communication MBARI May 2006) indicate that at present few figures have been identified, and that research is ongoing. However the answer would probably lie near 0.2 pH units (reduction). For the upper ocean, such a change would have relatively minor consequences in comparison against the deep-sea, where it is likely that 0.2 pH units will have important effects. This number, however, is only an estimate based on preliminary results, and MBARI do not yet have enough information on either the thresholds for tolerance for the major taxa of the oceans, let alone the influence of changes in pH or CO_2 on the dynamics of ocean communities and ecosystems.

Plymouth Marine Laboratory (PML) are currently undertaking large scale pilot plant experiments using mesocosyms that examine the impact of different concentrations of CO_2 upon the following indicators because they sustain primary production:

- Key benthic sediment dwelling organisms
- Biodiversity of sediments
- Biochemistry

PML are also involved in:

- Mesocosym experiments that examine impacts upon pelagic organisms (living in the middle depths or surface of the sea)
- Knowledge transfer and integration work package designed to provide information on the ecological effects of acidification to government, other policy makers, scientists, coastal managers, conservationists, NGOs and the public; this project is jointly funded by Defra and DTI.

The Leibnez Institute of Marine Sciences in Germany are currently examining the effects of higher CO_2 levels during the spring bloom on phytoplankton.

7.6.6 Conclusions & Gaps in knowledge

Research shows that that ocean pH is changing and will change in the future, and that marine organisms and marine ecosystems can be detrimentally affected by ocean acidification. Current knowledge indicates that CCS leaks (if any) could have a significant impact upon marine organisms surrounding the leak. This reinforces the need to ensure that the risk of leakage from CCS is minimised through proper site selection, design and monitoring. Note there is also uncertainty about impacts upon the onshore water environment.

Gaps in knowledge of the effects of ocean acidification upon marine ecology remain, because this area of science is young (less than 5 years old), and researchers are only beginning to understand the consequences of seawater acidification to the health, activity and long term survival or marine organisms. Main gaps include:

- Recovery of marine individuals, populations, communities and processes from impact
- Early life stages of ecologically or commercially important species
- Although science currently has some knowledge of specific ecosystem effects, the integrated effect of all process disruptions is unknown. Some current projects are attempting to address this, but much will remain outstanding without further research.
- Impacts of low pH/high CO_2 on marine bacteria and phytoplankton, fundamental elements of the marine food chain.
- There has been little research examining the impacts of pH on organisms other than aragonitic and calcitic (e.g. impact on nutrient speciationhttp://www.mccip.org.uk/arc/glossary.htm and therefore primary production and biodiversity) (Turley 2006).

Only when the above has been studied and understood, can sound environmental criteria be developed. As identified by Vattenfall (2005b), although the authorities are responsible for setting environmental criteria and limit values, since CCS is a new concept, input from all stakeholders is important and necessary in the development of acceptable criteria, such that consensus can be achieved.

7.7 On-Shore Environmental Effects of CO_2 Exposure

7.7.1 Introduction

CO_2 is a colourless, tasteless and odourless gas that occurs naturally in the atmosphere. The normal concentration of CO_2 in the atmosphere is 370 ppmv (0.037% atmospheric concentration) and at this level it is harmless and non-flammable (TOXNET). At concentrations levels above 2% (20,000 ppmv), CO_2 begins to have an effect on humans, vegetation and other organisms living in the exposed environment.

When reviewing literature relating to carbon dioxide and its effect on the environment, it was found that adequate information is available regarding CO_2 and its potential effects on human health. There is also information covering the effect of CO_2 on vegetation however the information is very genus specific. But there are large gaps in the literature relating to the effect of CO_2 on other organisms, a good example being the responses of micro-organisms in deep, sub-soil ecosystems to CO_2.

7.7.2 Effect of increased CO_2 on human health

Most people (those with normal cardiovascular, pulmonary-respiratory and neurological functions) can tolerate CO_2 exposure for several hours at concentration levels of 0.5 – 1.5% without harm (TOXNET). Long or high exposure however can significantly affect health. Increased CO_2 reduces the concentration of O_2 in the atmosphere, thus affecting the amount of air being inhaled and entering the bloodstream. Side effects such as nausea, increased heart rate, unconsciousness, headaches and loss of vision are well documented. An example of this is in Table 7.5 below (International Volcanic Health Hazard website):

Table 7.5: Health effects of respiratory exposure to carbon dioxide

Exposure limits (% in air)	Health Effects
2-3	Unnoticed at rest, but on exertion there may be marked shortness of breath
3	Breathing becomes noticeably deeper and more frequent at rest
3-5	Breathing rhythm accelerates. Repeated exposure provokes headaches
5	Breathing becomes extremely laboured, headaches, sweating and bounding pulse
7.5	Rapid breathing, increased heart rate, headaches, sweating, dizziness, shortness of breath, muscular weakness, loss of mental abilities, drowsiness, and ringing in the ears
8-15	Headache, vertigo, vomiting, loss of consciousness and possibly death if the patient is not immediately given oxygen
10	Respiratory distress develops rapidly with loss of consciousness in 10-15 minutes
15	Lethal concentration, exposure to levels above this are intolerable
25+	Convulsions occur and rapid loss of consciousness ensues after a few breaths. Death will occur if level is maintained.

Numerous studies like this exist and all show similar results. From these studies, vulnerable groups are identified as those with certain medical conditions, older people, children and people engaged in complex tasks.

A good example of the potential harm of a CO_2 release is the gas eruption at Lake Monoun, Cameroon in 1984. Thirty seven people in the immediate vicinity of the lake were killed and a number of dead animals were also found. Water samples were collected at depth and the dissolved gases were measured showing a CO_2 concentration of 97%. Pressure of CO_2 in the deep waters of the Lake was as high as 10atm (compared to normal atmospheric pressure of CO_2 of 0.0035 atm); thus it was concluded that a landslide into the crater triggered an overturn of the deep water. The CO_2, which was dissolved in the water at amounts far exceeding atmospheric pressure, effervesced leading to release.

In conclusion, the human health effects of CO_2 are well understood.

7.7.3 Effect of increased CO_2 on vegetation

Initially, increased CO_2 in the atmosphere is understood to have a “positive” impact on vegetation as it increases vegetation growth rates. Also, leaves lose less water as CO_2 concentration increases, meaning that vegetation is able to grow under drier conditions. However, such fertilization will generally be overwhelmed by the detrimental effects of elevated CO_2 in soils, because CO_2 fluxes large enough to significantly increase concentrations in soils (IPPC Benson and Cooke, 2005).

This can cause noticeable die-off and is exacerbated by the fact that CO_2 is 50% denser than air so it tends to migrate downwards, flowing along the ground and collecting in shallow depressions, potentially creating much higher concentrations in confined spaces. Table 7.6 below (adapted from IPPC 2005) shows the level of danger to plants relates to increased CO_2 in soil gas:

Table 7.6: Level of danger to plants induced by increased CO_2 levels

CO_2 in soil gas (%)	Level of danger
0.2 - 4% CO_2	None – normal concentration
Greater than 5%	Dangerous
Approaching 20%	Fatal - Phytotoxic

A valuable case study to note here is the plant die-off that occurred in 1989 at Mammoth Mountain in the USA where a resurgence of volcanic activity resulted in high CO_2 fluxes which caused trees for 40ha surrounding the volcano to die off within the following 8 years. Soil gas readings were taken in 1994 and results of up to 95% CO_2 by volume was discovered.

Practical studies have recently started at Nottingham University School of Biosciences which examine the effect of CO_2 on vegetation, and these are understood to be at the forefront of knowledge. The studies involve a soil gassing facility which will simulate the elevated soil CO_2 concentrations caused by a CCS leakage. By March 2007, preliminary data is expected to be available on three crops (pasture, linseed, barley) that will provide indication of CO_2 concentrations that cause harm to crops, and the data will be related to the time of exposure. Such results will be very relevant for EIA for onshore CCS projects. Additional research will be necessary to undertake more detailed studies in order for environmental impacts to be fully understood.

7.7.4 Effect of increased CO_2 on other organisms

The effect of increased CO_2 on other organisms, especially mammals, is similar to that of humans. Various studies have been done and these are shown in Table 7.7 below that is adapted from the studies on TOXNET.

Table 7.7: Effect of exposure of CO_2

Organism	Amount of CO_2	Time exposed	Result
Pig	68%	5 minutes	Death from asphyxia
Rat	6%	24 hours	Cardiac malformations in offspring
Unknown*	3%	Unknown	Elevated blood pressure and decrease in hearing acuity
Unknown*	5%	30 minutes	Signs of intoxication
Unknown*	7%	Few minutes	Unconsciousness
Dog	80%	1 minute	Respiratory movement ceased

* Document does not identify the specific organism tested.

A related case study is from the Alban Hills Volcanic District in Italy. The CO_2 asphyxiation of 29 cows in a heavily populated area prompted soil-gas studies to examine the distribution of the local health risk. The studies found that CO_2 concentrations at 1.5 m height above the ground in a residential area on the north-western flank of the Alban Hills episodically exceeded the occupational threshold of 0.5%. At 0.75 m height, 0.3-0.5% was frequently exceeded.

The responses of micro-organisms (microbes) in deep, sub-soil ecosystems to CO_2 do not appear to have been studied in detail. The overall functions of these communities are not well understood and need to be further researched.

7.7.5 Summary

Literature relating to CO_2 and its effect on human health is extensive and readily available.

Some data relating to the effect of CO_2 on plants and vegetation is also available and data for specific species can be found, although additional research will be necessary to undertake more detailed studies and further research in order for environmental impacts to be fully understood.

The main gap in knowledge occurs when researching the literature relating to the effect of CO_2 on other organisms. Whilst studies on mammals have been done, the reaction of smaller organisms, specifically microbes, to increased CO_2, still needs to be researched before a comprehensive assessment of increased CO_2 on the environment can be done, and also clarification of the importance of microbes is required.

7.8 Impact of Impurities in CO_2

Impurities likely to be present in CO_2 (IEA 2004) include H_2S, SO_2, NO_x, H_2, CO, N_2, O_2, Argon and the following trace elements could also be present: Mercury, Arsenic, Selenium. Better understanding of the impact of impurities is required, as they have practical impacts on CO_2 transport and storage systems and also potential HSE impacts.

7.8.1 Storage Issues

H_2S, for example, is considerably more toxic than CO_2 and well blow-outs containing H_2S may present higher risks than well blow-outs from storage sites that contain only CO_2. Similarly, dissolution of SO_2 in groundwater creates a far stronger acid than dissolution of CO_2; hence, the mobilisation of metals in groundwater and soils may be higher, leading to greater risk of exposure to hazardous levels of trace metals. While there has not been a systematic and comprehensive assessment of how these additional constituents would affect the risks associated with CO_2 storage, it is worth noting that at Weyburn, one of the most carefully monitored CO_2 injection projects and one for which a considerable effort has been devoted to risk assessment, the injected gas contains approximately 2% H_2S. Presently, insufficient information is available to assess the risks associated with gas impurities (IPPC 2005), and further evaluation is required to confirm effect of impurities on reservoir and cap rock.

It should also be noted that the economics of storage will be affected by the presence of lighter contaminants such as nitrogen or argon because they will occupy pore space thus reducing the availability for CO_2 storage.

When storage is accompanied by EOR there are potential problems:

- Injection of sour gas into a sweet reservoir thus rendering the reservoir sour;

- Depending on how sour the reservoir becomes there will be effects on the production equipment. Extra safety precautions or changes to construction materials may be required, but the industry has a lot of experience in dealing with sour reservoirs.

7.8.2 Transport issues associated with movement of contaminated CO_2

Presence of H_2S or SO_2 significantly increases the safety issues associated with transportation. H_2S has an anaesthetising affect, is extremely toxic and flammable and has long been recognised in the US as a serious health and safety concern. However, H_2S has well known and understood constituent properties with well established criteria.

7.8.3 Corrosion and Operational issues

H_2S, CO_2 and SO_2 all form corrosive acids in the presence of water. Therefore if the gas was not completely dehydrated there is a risk that acid would form and attack the pipes and equipment.

7.9 Monitoring of CO_2 Storage Projects

7.9.1 Introduction

It is possible that the CO_2 could leak or seep out of a reservoir, hence it is necessary to monitor the stored carbon:

- for health, safety and environment (HSE) purposes;
- for verification of quantity of CO_2 stored, for emissions trading & GHG inventory;
- to monitor the integrity of the reservoir.

The timescale over which monitoring is likely to be needed raises an issue in itself because it requires some consideration of the objectives of monitoring in the long term. The UK Department of Trade & Industry (DTI) commissioned a report into clean coal technology, and part of the report focused on the evolution of CCS projects and the changing nature of monitoring. Table 7.8 (below) is adapted from the report, and presents an overview of the possible monitoring objectives for storage projects:

Table 7.8: Project Evolution and Monitoring Objectives

Project Stage	Potential Duration	Possible Monitoring Objectives
Pre- injection	3-5 years	To develop a geological model To perform an EIA To develop predictive models of system behaviour To develop effective remediation strategies To establish baseline data against which future site performance can be compared
Injection	5-50 years	To verify the mass stored To determine the mass if any, that is seeping back to the ocean or atmosphere To meet local HSE performance criteria To provide stakeholder confidence, especially during early projects. To confirm, or otherwise, the accuracy of predictive Models
Post-injection	50-100 years	For the same reasons as during the injection stage plus: To provide evidence that the system will behave as predicted so that the site may be abandoned.
Post-closure	-	Not needed

Monitoring of CO_2 is covered in more detail in Appendix E, and summarised in this section.

7.9.2 Monitoring Techniques

A wide variety of techniques were identified from available literature. The following table provides an overview of the techniques that could be utilised to monitor reservoirs and detect CO_2 leaks:

Table 7.9: Approaches to Monitoring & Detection

Parameter	Monitoring approaches
CO_2 plume location	2D and 3D seismic reflection surveys. Electrical and electromagnetic methods. Land surface deformation (satellite imaging). Reservoir pressure monitoring. Wellhead and formation fluid sampling.
Early warning of site failure	2D and 3D seismic reflection surveys. Wellbore-surface and cross wellbore seismic measurements. Land surface deformation (satellite imaging).
CO_2 concentrations and fluxes at the ground surface	Real time IR based detectors for CO_2. Air sampling and analysis using gas chromatography. Eddy flux towers.
Injection well condition, flow rates and pressure	Borehole logs. Wellhead and formation pressure gauges. Wellbore annulus pressure measurements. Surface CO_2 concentrations near injection wells.
Solubility and mineral trapping	Formation fluid sampling using wellhead or downhole samples-analysis of CO_2, major ion chemistry and isotopes. Monitoring of tracers.
Leakage via faults and fractures	2D and 3D seismic reflection surveys. Electrical and electromagnetic methods. Land surface deformation (satellite imaging). Reservoir and aquifer pressure monitoring. Groundwater and vadose zone sampling.
Groundwater quality	Groundwater sampling and geochemical analysis. Monitoring of tracers.
Ecosystem impacts	Hyper-spectral geo-botanical monitoring. Soil gas surveys. Direct observation of biota.
CO_2 concentrations in vadose zone and soil	Soil gas surveys and gas composition analysis. Vadose zone sampling wells.
Micro-seismicity	Passive seismic monitoring.
Leakage from transportation pipelines	Visual inspection. Online flow monitoring. Pressure monitoring. Corrosion monitoring. Vapour sensing. Acoustic emissions. Fibre optics.

Source: adapted from Benson et al 2003.

[Note: the ‘vadose zone’ is the zone between land surface and the water table within which the moisture content is less than saturation (except in the capillary fringe) and pressure is less than atmospheric.]

As is evident from the table above, a wide variety of potential monitoring techniques exist. However not all are well known or fully developed. Table 7.10 (below) provides an indication as to the state of technological readiness of a number of the techniques:

Table 7.10: Measurement, Monitoring and Verification Technology

Technique	Detection method	State of technological readiness
Time lapse 4D multi- component seismic	Acoustic.	Well known.
Vertical seismic profiling.	Acoustic.	Well known.
Cross well seismic tomography.	Acoustic.	Well known.
Down hole micro-seismic.	Acoustic.	Developmental.
Electrical resistance tomography.	Electrical.	Developmental.
Electromagnetic induction tomography.	Electrical.	Prototype.
Soil gas sampling.	Chemical.	Well known.
Noble gas tracing.	Chemical.	Early testing.
Other gas tracing.	Chemical.	Early testing.
Well head detectors.	Chemical.	Prototype.
Brine sampling.	Chemical.	Well known.
Sub-surface and surface tilt meters.	Physical.	Developmental.
Airborne hyper-spectral imaging.	Optical.	Developmental.
Space based monitoring.	Microwave?	Proposed.

Source: adapted from a monitoring technology report (US Lawrence Livermore National Laboratory).

7.9.3 Gaps in the Monitoring Technology

Many monitoring technologies are mature and require little research and development, however they have not all been utilised in CCS projects and this would need to be demonstrated for the different types of CCS projects that are envisaged (DTI 2005), so that their strengths and weaknesses can be assessed. One of the main factors in this was considered to be a lack of awareness of the business opportunities, although all of the existing industrial scale projects and pilot projects have programmes to develop and test monitoring techniques.

The main monitoring technologies that were considered to be at the research/pre-demonstration or conceptual stages are as follows (DTI 2005):

- Borehole sensors for offshore monitoring/abandoned injection wells for long term deployment
- CO_2 sensors for shallow borehole and for groundwater measurements
- pH sensors for long term installations in boreholes at *in-situ* pressures, temperatures, salinities.
- Offshore sea bed microgravity techniques
- Testing of sea bed surveys (side scan sonar) to assess survey repeatability, and the resolution and capability of detecting CO_2 bubbles in water column
- Testing of sub-bottom profiling and shallow geo-physics repeatability
- Investigation into potential for microbial and bottom dwelling bioturbating communities as CO_2 leakage indicators.
- Response of crops and plants onshore to CO_2 leakage
- Offshore permanent autonomous CO_2 leakage monitoring networks
- Potential use of tracers to identify leakage.

According to the Carbon Sequestration Leadership Forum (CSLF), it is unclear to what extent the CO_2 measuring devices currently used by marine biologists can be adapted for benthonic settings, and very little is known about the use of changes in ecosystems or presence of indicator species to detect leakage of CO_2.

Standard procedures and protocols have not been developed but are expected to develop as technology improves (IPCC 2005). Draft new monitoring methodology has been proposed for some specific CCS projects that may be used as a base, but it should be noted that the methodology drafted is focussed on CDM CCS.

7.10 Capacity Building

Where national governments adopt mandatory requirements for conducting EIA for CCS projects, some countries may require capacity building to ensure full engagement and satisfactory review of the EIA. The establishment of a CCS Expert Panel (this may be set up within the CDM process – ERM 2006) setting out and disseminating industry best practices to support capacity-building in countries that need the expertise, would serve to enhance the robustness of CCS project development around the world.

7.11 Remediation of Leaking CCS Projects

Storage reservoirs will need to be selected and operated to avoid leakage using developed best practice. However, in rare cases, leakage may occur and remediation measures will be required, both to stop the leak and to prevent environmental impact. Some remediation techniques are available; the technique chosen will depend on the leakage route.

The remediation practices used for natural gas storage projects and disposal of liquid waste in deep geological formations have been surveyed and summarised (Benson and Hepple 2005, IPPC 2005). Remediation options were identified for most of the key leakage scenarios:

- Storage reservoir leaks;
- Leakage up faults and fractures;
- Shallow groundwater;
- Vadose zone and soil;
- Surface fluxes;
- CO_2 in indoor air, especially basements;
- Surface water.

Remediating CO_2 leakage from active or abandoned wells is particularly important, because it is a key leakage risk (IPPC 2005). Remediating blow-outs or leaks from injection or abandoned wells can be accomplished with standard oil and gas techniques, e.g. injecting heavy mud into the well casing. If the wellhead is inaccessible, a nearby well can be drilled to intercept the casing below ground level and then pump mud down the interception well. After control of the well is re-established, the well can be repaired or abandoned. Leaking injection wells can be repaired by replacing the injection tubing and packers. If the annular space behind the casing leaks, the casing can be perforated to allow cement injection behind the casing until the leak stops. If the well cannot be repaired, it can be abandoned.

Some remediation methods are well established, while others are more speculative. Additional detailed study is necessary to further assess the feasibility of applying these techniques to CCS projects, because there is no track record of remediation for leaked CO_2. Research is recommended to be based on realistic scenarios, simulations and field studies and some stakeholders suggest it would be beneficial to use an engineered controlled leakage event as a learning experience (IPPC 2005).

8.0 Long term issues of a CO_2 Storage Reservoir

8.1 Introduction

CCS projects will potentially require some form of long-term monitoring and management commitment from project operators or responsible authorities. This commitment should cover the operational phase and extend from 10's to potentially 100's of years post closure. It is possible that project operators will be unable to support long term monitoring and the host nation may have to take on this responsibility. The ESHIA approval process should therefore define ownership, monitoring, management, and remediation financial liability and consequence of failure liability. The exact financial, insurance and contractual mechanisms required for this are beyond the scope of an EIA methodology and are not therefore discussed further here, but need to be resolved at a UNFCCC, operator and host country level. For the purposes of the ESHIA methodology, specifically at least the following should be covered:

- Monitoring and reporting of:
  - potential CO_2 migration and potential loss through leakage
  - ecosystem response to any potential CO_2 migration or leakage
  - reservoir integrity (plugged wells, cap rock, etc).
- Prevention planning for (before potential leakage occurs):
  - intervention in potential significant CO_2 losses from degrading plugged well bores, infrastructure or monitoring facilities and weakened cap rock
  - intervention in lateral migration that could lead to leakage or impact
  - through routine maintenance of elements affecting reservoir integrity
  - site sterilisation marking (marking site area to prevent future intrusion).
- Mitigation planning for:
  - decommissioning and eventual abandonment by removal of all non-essential infrastructure such as pipelines etc
  - compensation of parties affected by leakage if it were to occur
  - mitigating ecosystem response to any potential CO_2 migration or leakage
  - mitigating loss of integrity in reservoirs
  - provision to compensate for CO_2 losses by purchase of CER's.

8.2 Analogues for CCS

.The industries most familiar with the issues that will be faced in CCS activities are the oil and gas and the nuclear sectors. Oil and gas companies have experience of stewardship of wells and their abandonment but not the long term stewardship of charged CCS reservoirs and sealed CCS wells. A parallel also exists with the experience from the nuclear industry for the long term management of radioactive waste, with the following issues:

- sealed underground storage
- long storage periods,
- leakage detection and ongoing monitoring requirements,
- site marking to indicate sterilisation to avoid future incursion
- remedial ownership and liability for hundreds to thousands of years.

Although subterranean nuclear waste management has the potential to provide useful direction for CCS projects, in reality the long term management of nuclear waste is still in its infancy.

Nuclear waste storage is still under research in relation to where and how waste should be stored in the long-term (i.e. over hundreds and thousands of years). It may, therefore, be difficult to address, through an EIA at this stage, the long term effects and post closure monitoring and management requirements of CCS project owing to the very long timeframes involved and the lack of a sufficiently developed analogues for comparison. It can be anticipated that there will be improvement in monitoring equipment in the future as well as a growing body of knowledge and experience that will accumulate over time. As a consequence, part of the EIA approval process could, therefore, be a requirement to reassess the closure and long term monitoring and rehabilitation requirements towards the end of operational life of any CCS project. The initial EIA could provide operator plans for monitoring and mitigation measures during the operational phase of the project.

To ensure that the long-term monitoring and management requirements are reasonable and to present the lowest CCS risk to future stakeholders the emphasis needs to be on very careful site selection, operational planning, control and monitoring and pre-closure reassessment of these requirements. This pre-closure reassessment should consider the inadvertent or accidental loss or leakage of CO_2 to atmosphere. If the loss were to occur and there was no impact on Climate Change cumulatively or ecosystem cumulatively for all CCS sites then the monitoring requirements can be selected appropriately. Part of this monitoring requirement determination would be risk assessment to determine the likelihood of loss of containment based on experience gained on a particular reservoir during the operational phase. If the likelihood is high or if lateral migration risk is high then more onerous monitoring and mitigation management planning and provision could be expected. Monitoring in its own right will not reduce the risk of leakage, but it can be used as an indicator of what can be expected and preventative measures put in place to reduce the risk of loss of containment.

Operational monitoring and post closure monitoring should cover at least the following:

- Ecosystem monitoring (determine if the media is being affected (e.g. water pH) by CO_2 release and if any biodiversity indicators are showing change or indicate potential loss of critical species.
- Lateral migration monitoring
- Loss monitoring
- Cap rock /well bore integrity monitoring

Monitoring frequency and type of monitoring requirement will need to be specified as part of the pre-closure monitoring plan to ensure that the requirements become contractually legally binding on the party that takes post closure ownership and liability responsibility. This requirement will need to be contained in the ESHIA regulations to ensure that it becomes part of the approval process. The extent of the legal requirement for these commitments is explored below.

8.3 EIA Legislative Coverage of the CCS Project Life Cycle

A review of the existing EIA legislation was conducted to determine how much of a project lifecycle must be considered by project developers as part of the EIA: for example, are they required to consider environmental impacts during decommissioning beyond end-of-life of an installation. The following table provides an overview of the findings:

Table 8.1: EIA legislation – an overview by country

Country / Organisation	Stages of a project's life covered by EIA legislation
Australia	Neither the EPBC Act nor the regulations contain reference to any EIA requirement to cover the entire lifecycle of a project. Pursuant to Article 3, the relevant Minister may make a declaration (in relation to approval for a development) only if satisfied that assessment of an action in the specified manner will include assessment of the impacts the action has or will have - or is likely to have.
Germany	Pursuant to Article 2 of the EIA legislation, a project is defined only in terms of construction (including alteration or extension) and operation - not the decommissioning phase of a project. Although an EIA has to be submitted before nuclear installation operators get approval for decommissioning to commence.
IFC	The operational policy contains reference to operation and implementation of projects only in relation to the environmental action plan (EAP). However, the IFC defines a project's EAP as consisting of the set of mitigation, management, monitoring, and institutional measures to be taken during implementation and operation to eliminate adverse environmental and social impacts, offset them, or reduce them to acceptable levels. No reference is made to decommissioning.
Japan	The only reference to lifecycle in the EIA legislation is in Article 1 which states that proper consideration is given to environmental protection issues by a corporation that is undertaking a project that changes the shape of the terrain or that involves the construction of a new structure, or that is engaging in other similar activities.
Norway	A project is defined only in terms of construction and operation. Although an EIA has to be submitted before nuclear operators get approval for decommissioning to commence.
UK	Under the EIA legislation, a project is defined only in terms of construction (including alteration or extension), not the operation or decommissioning phase of a project. However while the term 'operation' is not explicitly mentioned, consideration of impacts during operational phases is implied by virtue of the wording in the annexes. In relation to decommissioning, while it does not have to be included in the initial EIA, an EIA has to be submitted before nuclear installation operators get approval for decommissioning to commence.
USA	Neither the NEPA Act nor CEQ regulations contain relevant sections. However, a guidance document relating to preparation and content of an EIS contains the following reference to consideration of lifecycle: Describe each analyzed alternative - including no action - in sufficient detail so that its scope is clear and its potential impacts can be identified. Explanation: As appropriate, include the following elements in the description of each alternative – (1) *general project progression* (2) *pre-operational activities* (3) *operational activities* (4) *post-operational requirements* – description of reasonably foreseeable future requirements including site close-out and site restoration. Describe any related decontamination and decommissioning activities, including associated waste streams, to the extent practicable. Where only limited discussion of decontamination and decommissioning or other such distant future post-operational activities is possible, include a statement that a separate NEPA review may be needed before such future activities occur.
UNECE	The convention makes limited reference to elements of a lifecycle. The term 'construction' only appears in connection with construction of roads and power lines. The term 'operation' is not mentioned. In relation to decommissioning, while it does not have to be included in the initial EIA, an EIA has to be submitted before nuclear installation operators get approval for decommissioning to commence.
IAIA	The IAIA has produced 'best practice' guidelines for the EIA process, and one of the principles states that the EIA process should be applied 'as early as possible in decision making and throughout the lifecycle of proposed activity'.
Canada	The Environmental Assessment Act covers the whole lifecycle of a project. The act defines a 'project' 'in relation to physical work, any proposed construction, operation, modification, decommissioning, abandonment or other undertaking in relation to that physical work'.

Country / Organisation	Stages of a project's life covered by EIA legislation
European Directive	Under the Directive, an EIA should include a description of the project, including in particular 'a description of the physical characteristics of the whole project and the land-use requirements during the construction and operational phases'.
Netherlands	The regulations contain very limited reference to the lifecycle of a project. But the regulations state that an EIS should contain at least: a. a description of the purpose of the proposed activity; b. a description of the proposed activity and the manner in which it will be carried out. The guidance document associated with the regulations indicates that while consideration of 'operation' is not explicitly mentioned, project developers are required to consider it.
France	French legislation appears unclear because EIA requirements are covered by a number of different pieces of legislation, which makes it difficult to determine. Given that France is a member of the EU, it must abide by the spirit of the European EIA directive.

It is evident from the table above that very few countries or organisations require project developers to take a 'whole lifecycle' approach to conducting an EIA. To some extent one can understand why the end-of-life and decommissioning stage has been excluded during the project planning approval process because it could prove difficult to predict years in advance the kind of technology that will be utilised during the decommissioning phase. However, it should be noted that most countries and organisations make it clear that a separate EIA would have to be submitted before nuclear installation operators received approval to decommission and abandon a site, and this might be expanded to CCS projects.

ERM (2005) conducted a review of stewardship issues under existing legal frameworks (assuming that CCS projects were licensed under existing frameworks with minor alterations such as extending the definition of petroleum to include CO_2) as part of a broader look into permitting issues relating to CCS, and drew the following conclusions:

- UK: In relation to onshore storage of CO_2, they envisage that decommissioning activities would likely be included as part of the planning process, but would be expanded and refined prior to closure to ensure 'Best Available Technology' (BAT) is taken into account. They envisage that the authority responsible for issuing the permit for closure would include post-closure stewardship and outline the date that would trigger cessation of liabilities for the former site operator. In relation to offshore storage, ERM envisages that unlike decommissioning of oil wells for which there are a significant number of regulations, due to the long-term monitoring requirements and issues relating to stewardship, decommissioning of CCS wells will require even greater regulation.

- USA: To some extent, long-term monitoring of wells exists via the requirements laid down by the Underground Injection Control Programme (under which ERM envisages the early trial wells being authorised) and natural gas storage regulations. However, there is still some uncertainty around how long-term storage would be handled.

- Canada: There are currently no Federal regulations specifically related to abandonment of wells used for CO_2.

- Australia: There is a gap in relation to stewardship under existing frameworks. However, in relation to the Gorgon field, The Barrow Island Act (under which the CCS project will be authorised) requires the project developer to submit a detailed proposal regarding the eventual closure, rehabilitation and long-term management of the site to the authorities in Western Australia by 2008.

8.4 Stewardship of CCS Projects

The debate relating to how to ensure long-term management of CCS wells is ongoing with a number of options being considered to ensure that the reservoirs are monitored and managed over the long-term. The question also being raised is; how long an operator should be liable if CO_2 will need to be stored for 1000's of years? There is therefore, an issue relating to the liability of an organisation if it were to be acquired or merged, stopped trading or went into receivership.

Indeed, the issue of long-term stewardship of CCS is analogous to that of nuclear waste storage and radiological protection, whereby the International Commission on Radiological Protection (ICRP) states that 'the effective time period for engineering measures to influence (reduce) risks is limited (up to 1000 years post-closure) (ICRP, 2006). Assuming something of the same order of magnitude regarding stewardship of CCS, then quite clearly it is impossible to foresee the type of institutional structures which may be in place in 200 / 500 / 1000 years time and it is unlikely that public companies will be around for that long. As the ICRP states: 'there is no scientific basis for predicting the nature or probability of future human actions' (ICRP, 2006).

To ensure that there is some form of long-term stewardship ensured, it is proposed for consideration, that a scientific advisory panel under the directorship of say the UN or the UNFCCC be established for:

- Institutional capacity building relating to EIA and CCS
- Decision and scientific support for CCS authorisations and permits
- Assistance with evaluating monitoring reports
- Assistance with reviewing of monitoring storage integrity reports
- Over viewing of CO_2 losses from reservoirs
- Assist with developing long term monitoring and management regimes
- Oversee long term monitoring management and possible remediation
- Retaining and maintaining knowledge and records of CCS activities world wide.

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The expert scientific advisory panel will need to be composed of multi disciplinary team with experience in at least the following fields:

- EIA
- Reservoir engineering
- Green house gas and climate change
- Well engineering
- Subterranean gas monitoring.

Provision for handling long term liability needs to be developed, and below are some of the options for consideration, the practicalities of which will need further examination:

- the authority responsible for issuing permit for closure could require post-closure stewardship and outline the criteria or performance requirements that would trigger cessation of liabilities for the site operator (ERM 2005)

- On option is that a scientific advisory panel under the UN or UNFCCC be established for evaluating, monitoring storage integrity and administering a liability fund (long term).
  - This body would oversee and maintain a liability fund (part insurance, part investment) based on a risk of leakage.
  - The individual contribution from each project to a central fund would be less than project specific funds as the risk is spread (not all projects will leak).
  - Using a specific CCS ESHIA methodology for approval will allow the risk profile of projects to be compared fairly.
  - The tax could be applied on value paid for CO_2 to operators throughout operation. The liability fund will then have immediate value even during operation period (when operator has liability). This allows the fund to be invested and grown.
  - On hand over of liability, the fund will become part insurance and part investment as opposed to purely investment during operations.
  - This proposed mechanism also removes transboundary issues, operators storing CO_2 in same reservoir, migration of CO_2, as the international body will take on the long term liability.
  - This central fund will have immediate access to cash to address any issues. It is the speed of the response that will minimise the liabilities and the costs associated with remediation of a leaking reservoir.

Other options for managing liability (IETA paper 7/2/06), are as follows:

- Creating longer-term liability for project developers/operators to buy GHG compliance units such as CERs in the event of seepage emissions as part of a CCS project approvals process (e.g. a permitting/licensing regime for CO2 storage operations);
- Flagging CCS-specific CERs or issuing temporary CERs etc which would be cancelled and require replacement, *pro rata*, in the event that seepage occurred. This would pass liability for seepage emissions on to the buyer of the CERs (“buyer liability”); or,
- Applying a default or discount factor to account for future seepage emissions so that either a portion of CERs are not issued, a portion are set aside in a credit reserve, or a portion of the revenue from CERs sales is set aside in a contingency fund. This could serve to essentially cap liability for all actors in the market at the chosen default or discount rate.

Whatever the approach, the most important consideration is that the structure of liability provisions needs to be practical and predictable for both project developers and the wider GHG market.

8.5 CO_2 Permanence

The issue of permanence or the lack of leakage or loss is widely debated. The principle of ‘permanence’ is simply that it is likely there will be zero or negligible leakage out of a geological store, so long as potential CO_2 storage sites are subject to stringent site characterisation and selection along with long-term monitoring. Those favouring this position on permanence also argue that all CO_2 successfully injected into storage should be considered permanent, if a seepage event does occur it will be monitored and remediated.

This places the focus on the upfront engineering design and site characterisation. With the current lack of knowledge of long term storage of CO_2 under charged reservoir conditions it is unlikely that all leakage could be avoided through design and characterisation. It is also unlikely that all migration and potential leakage pathways can be mitigated and controlled. Permanence and zero leakage are therefore unlikely to be realistic and from the perspective of accurate public consultation and transparency, caution is advised for using these terms for CCS generally. All human activity has risk associated with it, while permanence and zero leakage suggest no risk - which will cause public acceptance mistrust. Permanence and zero leakage are goals but unlikely to be totally risk free therefore unlikely to be reality.

Assuming zero leakage in the long term based on a predictive science with no true CCS project running for any reasonable length of time to verify the science, would appear to be undermining the responsibility ethos underlying CCS and the whole motivation for improving the EIA technology and methodology. It is likely that there will be leakages, at least from some reservoirs, and it is therefore proposed that a reservoir migration and leakage risk profile be created. This can then also be used to determine the type, nature and frequency of monitoring that may be required. This will allow the monitoring and management plan that is required as part of the ESHIA to be created and form the basis of the long term Storage Performance Assessment (SPA) that could be linked to the requirement under CDM, for example, where it needs to be demonstrated that CO_2 stored by a project are is verifiable and validated. This validation and verification is inherently part of the CDM process and could be extended to include the requirements for long term monitoring of the CCS reservoir. The ownership and handover of ownership could be based on this risk profile. This will safeguard the intent of taking responsibility for pollution as well as ensure the high standard of the EIA which will reduce the risk profile of any project. It will also ensure that long term knowledge and understanding of reservoir behaviour with regard to CO_2 migration and leakage is understood.

8.6 Long-term monitoring based on risk profiling

Taking the analogy of the nuclear waste issue again, ICRP (2006) talks of the ‘Best Practicable Means’ (BPM) to assess appropriate management measures to reduce long-term (radiological) impact and associated uncertainties, in order to investigate options available for the reduction of long-term risks associated with a site and to inform future decisions on site management. One of the options to be considered (Option 1) could be equally pertinent to long-term stewardship of CCS: ‘extending the proposed period of institutional control from 100 years after cessation of disposals to a nominal 1000 years to increase the performance of post-closure engineering through monitoring and maintenance’.

The ICRP also makes some predictions regarding timescales for long-term control and monitoring. In terms of CCS stewardship, similar timescales and organisational provisions could be summarised as follows:

- 100 years: post-operational management phase, whereby active control and monitoring of post-closure engineering;
- post-100 years: withdrawal of active operator controls (when it is confirmed that any residual impact no longer requires active control of the site);
- post-200 years: institutional control phase (passive control) whereby planning controls would continue to minimise the potential for human intrusion (duration could be for 100s of years);
- Undefined: post-institutional phase, recognising that in the longer-term, institutional controls may not continue to exist.

Herein lies the conundrum that the very term ‘long-term monitoring’ of CCS in depleted oil and gas fields, or deep saline aquifers, can be as difficult to define with any more precision that of monitoring nuclear waste repositories over the longer-term. However, the principal need will nevertheless be to actively monitor the seal integrity of any underground CCS site over a timescale of the order of perhaps the first 100 years, and similarly provide suitable monitoring mechanisms to detect CO_2 seepages or migration. In addition, it is also argued that a 'best practice' protocol for Storage Performance Assessment (SPA) should be developed.

8.7 Discussion

The review of the EIA regulatory frameworks revealed that very few countries currently require a 'whole lifecycle' approach to environmental assessment, covering decommissioning and beyond (stewardship). The nuclear industry is however specifically noted in some legislation to cover decommissioning and this could also be used as a basis for CCS. If CCS projects are to be approved under the existing EIA frameworks, they would probably need to be amended in recognition of the fact that the liability of an operator will extend beyond a timeframe conceivable by the majority of organisations (apart from the nuclear industry). As a basis for debate, this period could be between 100-1000 years plus.

Most frameworks require a second EIA to be submitted in advance of commencement of decommissioning operations, because BAT philosophy will capture the best available knowledge and techniques at that point in time. However, the US takes the view that organisations should have some idea of the processes likely to be involved in end-of-life operations and hence should be able to formulate a broad plan that could be refined closer to the time. In the mining and waste industries in some countries such as South Africa, there is a requirement to consider decommissioning and remediation in the initial planning and EIA as it leads to better choices for proposed developments which minimise the operational footprint and reduce the amount of wastage at the end of life.

ERM (2005) suggest that the regulators look to the oil and gas industry for guidance where organisations make a commitment to use BAT at the time of decommissioning as opposed to committing to a specific technique up-front. For the purposes of the CCS ESHIA it is proposed that a broad plan is presented as part of the first assessment and that a second more detailed assessment be prepared before decommissioning. This second assessment can use the knowledge gained on migration during the life of the reservoir and use this to prepare a leakage and permanence risk profile that can then be used to determine the requirements for monitoring and management provision in the long term.

CCS is still very much in its infancy and as yet no decisions have been made as to how and for how long operators are going to be held liable. The objective of this discussion is to highlight to what extent the lifecycle of a project is covered by an EIA at present and to set out an overview of the debate relating to such stewardship with some possible ways forward on how this can be addressed.

9.0 Summary of Key Findings

9.1 Regulation

- Regulatory frameworks for EIA & SEA in countries around the world are similar, but not the same.
- CCS projects are not currently specifically mentioned in EIA & SEA frameworks because CCS is a relatively new technology. However, CCS projects may be captured under other industries covered by EIA/SEA legislation. In order to have regulatory certainty, it is recommended that either existing legislation is adapted or alternatively to develop a legislative framework specific to CCS. EIA legislation could be clarified at the same time to identify if pilot scale CCS developments require an EIA.
- Certain other environmental legislation may also need amendment e.g. OSPAR, IPPC, Landfill Directive, Groundwater Directive. Note that storage of CO_2 under the seabed will be allowed from 10 February 2007 under amendments to the London International Convention and Protocol, which governed dumping of wastes at sea. The OSPAR Convention, which provides further protection to the marine environment of NE Atlantic, is expected to follow suit. Studies are underway to resolve these regulatory issues.
- Some countries may require capacity building assistance to ensure full engagement and satisfactory review of the EIA.

9.2 ESHIA & Kyoto Protocol

CDM only requires an EIA if appropriate national law requires it. Based on the uncertainty detailed above, it is recommended that:

- Validation and Verification Manual be updated to include specific requirement for an EIA in the validation of CCS projects, regardless of national requirements.
- Schemes specify international guidelines should be followed (guidelines are not presently available).
- Align the requirements of CCS EIA with the requirements of CDM & JI.

9.3 Environmental Guidelines – general needs

DNV recommends that international guidelines for assessment of CCS projects be developed for the entire CCS chain, with particular focus on injection and storage. A framework for the environmental component of such guidelines is presented in this report (see Figures 3.1 and 5.2). General knowledge gaps relating to this framework are summarised in Table 6.1.

It is recommended that the environmental assessment guidelines incorporate the following requirements and guidance:

- An ***Integrated Environmental, Health and Safety assessment (EHSIA)*** approach for CCS projects where a significant release of CO_2 could impact health and safety (e.g. onshore).
- A risk based *source-pathway-receptor* approach.
- The identification of projects with a high risk of early closure, as this would prevent the full environmental benefits of CCS being realised (Section 5.2.2).

- The evaluation of a carbon balance across the whole project life cycle (Section 5.2.3).
- Guidance covering all EHSIA process steps.
- Identification of environmental resources to be covered in an EHSIA, and the specific information that, as a minimum, should be included under each environmental resource based on the risks identified in this report.
- Clear regulatory guidance on the play-off in priorities between local pollution concerns versus climate change concerns via some form of 'risk-benefit' approach.
- Require operator commitments for monitoring, including post-closure monitoring within EHSIA.
- Provision for handling long term liability (Chapter 8). If CCS projects are to be approved under existing EHSIA frameworks, they will need amending to accommodate this issue.
- Review of SEA/EHSIA needs at regular periods as knowledge improves.
- For nuclear projects, many countries demand a separate EHSIA for submission before operators receive approval to decommission. It is recommended that guidelines require the expansion of this concept to CCS, to ensure Best Available Technique (BAT) is applied.
- The EHSIA should include the results of a Storage Performance Assessment (SPA) as an inherent part of the EHSIA (see section 7.3.5). As such, an implicit part of ESHIA will be site characterisation and performance.
- Guidance on whether CO_2 emissions from the additional oil recovered as part of an EOR project would need to be assessed in an EHSIA.

9.4 Specific Needs & Information Gaps

Information necessary to undertake EHSIA of the first two stages of CCS **(*capture and transport*)** is relatively well defined and does not have significantly different needs than for the many EHSIA's conducted every year, and does not involve technologies significantly different from those well established and in commercial use today. Areas where further information is required include:

- Dispersion modelling of supercritical CO_2 releases – this is currently not well understood.
- Additional R&D is needed to improve knowledge of emerging concepts and technologies for CO_2 capture, in particular to help demonstrate the reliability of the environmental performance of capture systems on a large scale.

It is considered that the information necessary to undertake environmental assessment of the ***injection and storage*** of CO_2 stage of a CCS project is *not well defined*, and has many uncertainties. The uncertainty relates primarily to the risk and impact of CO_2 leakages, whether from faults, well blow outs, cap leaks, poor injection etc. In many cases the likelihood of such leaks and their size is not currently well defined and the impact that such leaks would have on the environment is not clearly understood. Information gaps, needs and uncertainties are summarised in sub-sections below. Detailed information is provided in Chapter 7 and Tables 7.1 and 7.2 in the main body of the report.

9.4.1 Risk of CO_2 Release during Injection & Storage

The following needs and information gaps have been identified:

Exploration & Site Selection

- There are currently no minimum national or international standards for site selection (storage reservoir); it is recommended they be developed.
- Improved understanding is necessary of the proximity of major CO_2 sources to suitable storage sites to facilitate decision-making about large scale deployment of CCS.
- Site characterisation efforts during the reservoir site approval stage will need to be minimised because it is undesirable to pepper the ground with exploration wells, as this can reduce the integrity of the potential reservoir site. However, a site with no existing boreholes will need to drill some exploration wells. The key is good understanding of the condition of the wells and to seal them appropriately. A strong, clear and flexible regulatory regime needs to be developed to control and manage these risks.

Injection

More experience from CCS trials is required to increase confidence in utilising data from oil and gas injection wells.

Storage Reservoirs

Possible CO2 escape pathways are:

- Abandoned wells/wellbore failure
- Diffusion flow through caprock (via faults, or by buoyancy through permeable zones)
- Dissolution and transport of CO_2 charged waters in the aquifer by groundwater flow

In general, there is restricted available quantitative data on probabilities and amounts of leakage from CO_2 geological reservoirs, although IPCC (2005) note that the fraction of CO_2 retained in *appropriately selected and managed geological reservoirs* is very likely to exceed 99% over 100 years and is likely to exceed 99% over 1,000 years.

The main difficulties for a quantified assessment of generic risks of CO_2 release from reservoirs are the lack of detailed long term monitoring of field trials or modelling done to date, and the fact that risk conditions are extremely site specific. Consequently, the implementation of more pilot and demonstration CCS storage projects is important to improve understanding. However, closely related industrial experience and scientific knowledge (primarily from the oil and gas sector) could serve as a basis for appropriate risk management.

There are currently no guidelines available that provide a generic methodology to quantify probability and quantity of CO_2 release risk, and it is recommended that an Expert Panel develop such a document. To be able to produce a risk assessment of CO_2 release that is trusted and consistent, a systematic methodology is recommended; note that some work in this area has commenced in a current study (CO2STORE). It is recommended that the guidelines include consideration of whether:

- minimum lateral distances of populated areas from reservoirs are advisable;
- the following types of areas should be screened out or have their priority for CCS development downgraded:
    - areas with endangered species of plants and animals, and conservation sites
    - areas with low turnover lakes and lakes with sensitive communities
    - areas with significant sources of groundwater located nearby
    - areas containing many old or abandoned wells.

Storage Performance Assessment (SPA)

The risk assessment will need to incorporate the results of the Storage Performance Assessment (SPA) in the EHSIA, such that an implicit part of the EHSIA is reservoir characterisation and performance assessment. It could be possible to set minimum requirements (via an expert panel) for best practice SPA in order to get a good practice EHSIA.

To support a good quality SPA, the following technical areas will need to be addressed as they are currently not fully understood, as discussed in more detail in Section 7.3.4:

- Mapping the Underground: Clear minimum standards are required for comprehensive mapping of a reservoir and surrounding area during baseline data collection.
- Identifying Discrete Potential Leakage Paths in the Underground: it will be necessary to introduce a permitting regime capable of handling the limitations of automated seismic techniques.
- Grid of CO_2 Flow Simulators: it is a challenge to obtain the necessary resolution of predictive simulation models of dynamic CO_2 flow to adequately represent fluid movement.
- Modelling of Uncertainty in Leakage in the Underground: traditional tools for modelling uncertainty may be insufficient.

9.4.2 Environmental Issues

The following topics have been examined in detail in Chapter 7 to identify the needs and information gaps that need to be addressed to be able to conduct a competent EIA:

- Modelling of CO_2 releases: Models are being developed to investigate CO_2 leaks from reservoirs (both diffuse and point sources) to the marine environment. They examine CO_2 dispersal and environmental impact of different quantities of CO_2 leaks over different time periods under different scenarios. Further research is necessary.
- Effect on marine environment: Research shows that marine organisms and marine ecosystems, including coral reefs, can be detrimentally affected by ocean acidification. Current knowledge shows that any CO_2 leaks from CCS could have a significant impact upon marine organisms surrounding the leak. This reinforces the need to ensure that the risk of leakage from CCS is minimised through proper site selection, design and monitoring. Note there is also uncertainty about the impact upon the onshore water environment.
- Gaps in knowledge of the effects of ocean acidification upon marine ecology remain because this area of science is relatively young.
- Environmental criteria: Sound environmental criteria and environmental quality standards need to be developed.
- On-Shore Environmental Effects of CO_2 Exposure: Human health effects of CO_2 are well understood on healthy populations, but some knowledge gaps exist regarding the effect of CO_2 on plants, vegetation and ecosystems. The reaction of smaller organisms, specifically microbes, to CO_2 needs further research, in addition to clarifying the importance of microbes.
- Impurities: Better understanding of the impact of impurities in CO_2 is necessary.
- Monitoring of CO_2 Storage Projects: Although many monitoring technologies are mature, they have not all been demonstrated for CCS projects, and further development is necessary for less mature technologies. For example, very little is known about the use of changes in ecosystems or presence of indicator species to

detect leakage of CO_2. Standard monitoring procedures and protocols require development.
- Remediation: Some remediation methods are well established, while others are more speculative. Additional detailed study is necessary to further assess the feasibility of applying these techniques to CCS projects.

9.5 Liability

Provision for handling long term liability needs to be developed; below are some options for consideration (Chapter 8), the practicalities of which need further examination:

- The authority responsible for issuing permit for closure could require post-closure stewardship and outline the criteria or performance requirements that would trigger cessation of liabilities for the site operator (ERM 2005).
- One option is that a central scientific advisory panel be established for evaluating and monitoring storage integrity and administering a long term liability fund based on leakage risk. It would have the following advantages:
  - The individual contribution from each project to a central fund would be less than project specific funds because the risk is spread.
  - Using a specific CCS ESHIA methodology will allow comparable risk profiles.
  - The central fund would have immediate access to cash to address any issues.

Other options for managing liability (IETA paper 7/2/06) include:

- Creating longer-term liability for project developers/operators to buy GHG compliance units such as CERs in the event of seepage emissions as part of a CCS project approvals process (e.g. a permitting/licensing regime for CO_2 storage operations);
- Flagging CCS-specific CERs or issuing temporary CERs etc which would be cancelled and require replacement, *pro rata*, in the event of seepage. This would pass liability for seepage emissions on to the buyer of the CERs ("buyer liability"); or,
- Applying a default or discount factor to account for future seepage emissions so that either a portion of CERs are not issued and are set aside in a credit reserve or contingency fund. This could serve to essentially cap liability at the chosen default or discount rate.

Whatever the approach, it is important that the structure for liability provision needs to be practical and predictable for both project developers and the wider GHG market.

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MANAGING RISK DNV

STEPS IN THE EIA PROCESS.	AUSTRALIA Environment Protection and Biodiversity Conservation Act 1999 and Regulations made under the Act in 2000 (Statutory rules 181 as amended).	CANADA (Canadian Environmental Assessment Act 1992, amended in 2003).	EUROPEAN DIRECTIVE (85/337/EEC as amended by 97/11/EC).	FRANCE. Environmental Code.	GERMANY Environmental Impact Assessment Act 2001.	JAPAN Environmental Impact Assessment Law 1997.	NETHERLANDS Environmental Management Act and Regulations.	NORWAY Environmental Impact Assessment Regulations 2005.	IAIA Principles of EIA Best Practice.	IFC Operational Policy 4.01	UK The Town and Country Planning (Environmental Impact Assessment) (England and Wales) Regulations 1999. SI 99/293	UNECE Convention on Environmental Impact Assessment in a Transboundary Context (Espoo 1991).	USA (National Environmental Policy Act 1969, as implemented by Executive orders 11514 & 11991 and the Council on Environmental Quality Regulations 1978, and regulations or guidelines promulgated by each Federal agency).	Combined Best
Screening.	Referral stage: The project proponent or the State refers the project to the relevant department/ Minister to determine whether they need EPBC Act approval. There are two outcomes:1. EIA is not required. 2 An EIA required. The Australian Government has established bilateral agreements with some states and territory governments to accredit the assessment process used by the state/ territory. If EPBC approval is needed in addition to state/ territory approval it may be possible to undertake just one assessment if a bilateral agreement exists- if not it may be possible to accredit the state/territory process for individual proposals. A determination will be made as to what level of assessment is required. There are 4 options: Assessment based on preliminary documentation; Public Environment Report; Environmental Impact Statement; Public Inquiry. All levels of assessment involve a public comment phase.	The first step in the EIA process involves screening to determine if an EIA is required. The responsible authority can choose one of four EIA options: screening report; comprehensive report; mediator review; or a panel review. If an EIA is required, further screening takes place to determine the scope of the screening report or scope of the comprehensive study (s14-16). Pursuant to s18, where the responsible is of the opinion that public participation in the screening project is appropriate or required by regulation, the responsible authority shall provide the public with an opportunity to examine and comment on the screening report. If screening concludes that further investigation is necessary, the responsible authority refers the project the Minister of the Environment for a referral to a mediation or panel review (3rd and 4th EIA tracks established under the act- 1st and 2nd being Self directed screening or comprehensive report). In the case of a comprehensive study, the Minister determines whether the project can be referred back to the responsible authority for action, or whether further investigation is required.	Notification to competent authority and screening to determine whether an EIA is required. (Pursuant to the legislation member states are required to adopt measures to ensure that projects likely to have significant effects on the environment by virtue of their nature, size or location are made subject to a requirement for development consent and an assessment with regard to their effects).	The Code contains a presumption that all public and private projects require an EIA. However the code also includes what are called "exclusion thresholds". The thresholds are used to screen out those projects that do not require an EIA.	Pursuant to article 3a, the competent authority, upon application by the project developer or in response to a request pursuant to article 5, shall on the basis of suitable details about the project and information of its own determine whether under article 3b-f an obligation exists to carry out an EIA for a project. Annex 1 provides an overview of the projects that require an EIA. Annex 2 contains a list of screening criteria. Where a screening determination has been made, such determination will be made accessible to the public in accordance with the provisions of the Act.	Screen to determine whether an EIA needs to be conducted (Screening conducted by the relevant administrative agencies that authorise the projects) (Chapter II, section 1 of the EIA law).	A development proposal is screened to determine whether an EIA is mandatory required by virtue of the nature of the project (activities designated by council which may have serious, adverse effects on the environment); or whether an EIA may be required (the proposal is reviewed with reference to the thresholds and criteria laid down by an order in council in order to determine whether an EIA is required).	Proposed planning programmes should be circulated to the relevant authorities and special interest organisations for consultation and be made available for public consultation.	Screening best practice dictates that the process should be used to determine whether or not a proposal should be subject to an EIA and if so at what level of detail.	Prior to screening, OP 4.01 provides for "Early review". The Investment Department of the IFC requests that the Environmental Division allocates specialists to a proposed project. Early involvement enables the Environment Division to provide guidance on environmental and social requirements. The next stage is "project screening". The purpose of the stage is to determine the nature of the environmental assessment. Screening is carried out at the time the project is identified. The project team determines the nature and magnitude the proposed projects potential environmental and social impacts and assigns the project to one of three categories: *Category A* : a full EIA is required. Projects are those expected to have "adverse impacts that may be sensitive, irreversible and diverse". *Category B:* Although a full EIA is not required, some environmental analysis is necessary. Projects are those that have impacts that are "less significant...not as sensitive, numerous or major or diverse. Few, if any of these impacts are irreversible and remedial measures can be easily designed". *Category C:* No EIA or other environmental analysis is required, such projects entail negligible or minimal direct disturbance to the physical setting.	Developments that fall under Schedule 1 of the Regulations always require an EIA. Developments of the type listed in Schedule 2 which meet one of the relevant criteria or exceeds one of the relevant thresholds or is located in a "sensitive area" may be subject to an EIA. In relation to determination of whether an EIA is required, the proposer may request that the relevant local authority adopt a screening opinion (reg 5(1)) or the Secretary of State (reg 6). In making a determination, the local authority/ Secretary of State must take into account the relevant screening criteria in Schedule 3 to the Regulations, for example, characteristics of the development, location, and characteristics of the potential impact. The Secretary of State may make a screening direction irrespective of whether he has received a request to do so (reg 4(7)).	The Convention does not mention a screening procedure. The first step in the procedure in the convention relates to notification of proposed activities that may have transboundary effects.	The National Environmental Policy Act (NEPA) requires all agencies of the federal government to include in every proposal for "major federal actions significantly affecting the quality of the human environment" a detailed statement on the environmental impacts of and alternatives to the proposed action. The Federal Agency overseeing NEPA compliance of a project will undertake a preliminary environmental analysis to determine whether there is a need for an EIS, whether the environmental impacts are clearly insignificant - thus removing the need for an EIA or whether an environmental assessment (EA) should be prepared so that the significance of the impacts can be more clearly identified. Depending on the findings of the EA, and EIS may be required because the unmitigated impacts are significant, or the Agency may decide that an EIS is not necessary- in this case they issue a "Finding of no significant impact" (FONSI).	Screen to determine whether or not the project requires an EIA. Consultation with interested parties, governments or authorities as required.
Scoping.	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	The aim of the scoping process is to determine the items and issues to be addressed in the EIA (terms of reference). The developers should outline the methods to be used in the course of the EIA. Interested and affected parties should be given the opportunity to comment on the scope of the EIA.
Analysis of Alternative Options.	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	Developers should include a description of the alternatives to the proposed project. The description should include an assessment of the potential impacts and potential mitigation. The option of no action should be considered.
Project Description.	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	The developer should include a comprehensive description of the project in the EIA. The description should cover the lifecycle of the project (i.e. construction, operation, maintenance, decommissioning). It should include an overview of: size, location, timetable of the project, proposed land use, nature and quantity of construction materials, description by type and quantity of the expected residues and emissions (noise; water; air; soil pollution; vibration; light; heat etc).
Baseline Review.	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	The objective of the baseline review is to describe the state of the environment (where relevant) as it is prior to commencement of project operations. The review should describe the flora & fauna; water (aquifers; water courses; shore lines; existing discharges); soil (geology; geomorphology; including seismic characteristics); air (quality; climatic factors); architectural, historic and cultural heritage.
Legislative Review.	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	Developers should include in the documentation an outline of the policy, legal and administrative framework within which the EIA is prepared. It should include all relevant legislation at a local, state/ territory, regional national and international level that could affect the proposal.
IMPACT ASSESSMENT. Impact Identification.	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	The developers should identify all aspects of the project that could impact upon: environmental or biophysical factors; socio-economic factors e.g. health, culture, lifestyle, gender. Impacts should include short- medium and long-term effects; positive and negative; primary and secondary; cumulative; permanent and temporary; escalation/ domino effect; reversible and irreversible; and inter-relationships between them.
Impact prediction.	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	The impacts identified in the preceding stage should be quantified via qualitative, quantitative and semi- quantitative techniques. Developers should consider frequency, duration, magnitude, risk etc.
Impact Significance.	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	In determining the significance of activities, developers should consider the size of the project; location (near SSSI's); and the nature of the effects. Impacts should be screened and prioritised accordingly.
Impact Mitigation.	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	Developers should provide a description of the measures which will be taken to avoid; reduce; or remedy significant adverse effects. The description should include an overview of the predicted or expected cost effectiveness of the measures; the statutory or policy basis of the measures; cost of mitigation.
Environmental management Plan.	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	The environmental management plan should contain a framework for the continuing management and mitigation of the project including consideration of who will be responsible.
Environmental Monitoring Programme.	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	The environmental monitoring programme should provide a detailed programme for monitoring appropriate for the nature, location and size of the sequestration well. Developers should consider the nature of monitoring techniques to be used (there may possibly be minimum standards for pipelines).
Reporting.	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	The developers should prepare a draft EIA report containing a non-technical summary of the aforementioned information.
Review.	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	The draft report should be submitted to the relevant authorities/ bodies for review. It should also be made available for review and comment by interested and affected parties and the general public. The comments should be fed back to the developers which should finalise the report in light of the comments received. The responsible authority should review the final documentation and make a decision in light of the report and consultation. Conditions may be attached to the approval e.g. relating to mitigation measures to be taken.
Project Implementation & operation (including regular environmental monitoring).	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	Developers should engage in monitoring and environmental management as per the plan. The aim of monitoring is to assess the effectiveness of the mitigation measures and to identify unforeseen effects. The responsible authority should ensure that any conditions attached to the approval are being met.
GAPS in FRAMEWORK (non CCS Specific)	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	
CCS SPECIFIC GAPS: 1. Is CCS project covered by EIA legislation?	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	
CCS SPECIFIC GAPS: 2. Does EIA include stewardship of CCS project? What project lifetime is covered by EIA? Does legislation require provision of decommissioning plan?	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	
CCS SPECIFIC GAPS: 3. Is monitoring a requirement?	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	
CCS SPECIFIC GAPS: 4. Does legislation require use of available guidelines?	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	
Note.	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	

NOTE: DNV are environmental consultants, not environmental lawyers; this document does not represent a legal review, rather a general review of the frameworks.

STEPS IN THE SEA PROCESS.	Australia. Environment Protection and Biodiversity Conservation Act 1999 and Regulations made under the Act in 2000 (Statutory rules 181 as amended).	CANADA. Cabinet Directive on the Environmental Assessment of Policy, Plan and Program Proposals (and accompanying implementation guidance).	EUROPEAN DIRECTIVE. SEA Directive 2001/42/EC
Screening.	Section 146 includes explicit provision for discretionary strategic assessment of particular actions that may be carried out under a proposed policy, programme or plan. The Minister may agree in writing with a person responsible for the adoption or implementation of a policy, plan or programme that an assessment be made of the impacts of actions under the policy, plan or programme on a matter protected by a provision of Part 3. The agreement may also provide for the assessment of other certain and likely impacts of actions under the policy, plan or programme if: the actions are to be taken in a State or self-governing territory; and the appropriate Minister of the State or Territory has asked the Minister administering section 146 to ensure that the assessment deal with those impacts to help the state and the actions are to be taken by any person for the purposes of trade or commerce between Australia and another country or are actions whose regulation is appropriate and adapted to give effect to Australia's obligation under an agreement with one or more countries.	Government ministers expect an SEA of a policy, plan or programme proposal when the following two conditions are met: the proposal is submitted to an individual minister or Cabinet for approval; and, implementation of the proposal may result in important environmental effects, either positive or negative. Departments and other agencies are also encouraged to conduct SEA's for other policy, plan or programme proposals when circumstances warrant. An initiative may be selected for assessment to help implement departmental or agency goals in sustainable development, or if there are strong public concerns about possible environmental consequences. As early as possible in the development of a proposal the analyst should determine whether important environmental considerations are likely to arise from implementing the plan, policy or programme.	Pursuant to article 3, member states are required to ensure that an environmental assessment is carried out for all plans and programmes for projects listed in paragraph 2. Member states are also required to determine whether plans and programmes other than those referred to in paragraph 2 which set the framework for future development consent of projects are likely to have significant environmental effects (article 3(4)). Screening is to be done on a case by case basis or by specifying types of plans and programmes, or by a combining both approaches (article 3(5)). Member states are required to ensure that their conclusions pursuant to paragraph 5 (determination of significant environmental impact), including the reasons for not requiring an SEA are made available to the public (article 3(7)).
Scoping.	The agreement must provide for the preparation of draft terms of reference for a report on the impacts to which the agreement relates and the publication of the draft terms of reference for public comment for at least 28 days and the finalisation of the terms of reference to the Minister's satisfaction, taking into account the comments received on the draft terms of reference. Pursuant to article 146, sub-section 2, the Minister decides on the level of assessment.	Ministers expect the SEA to consider the scope and nature of the likely environmental effects, the need for mitigation to reduce or eliminate adverse effects and the likely importance of any adverse environmental effects, taking mitigation into account.	Whilst not specifically mentioned as a required element, under article 5(4), the authorities referred to in article 6(3) (authorities to be consulted) are required to be consulted when deciding the scope and level of detail of the information which must be included in the environmental report.
Analysis of Alternative Options.	The preliminary information regulation (5.03, schedule 3) require proponents to provide details of alternatives to the proposed action, including a description of each alternative; how they would be undertaken; the option of no action; relative effect of the alternatives on the impacts of the relevant action. For those proceeding via a PER or EIS, (regulation 5.04), proponents must include a description of each alternative including no action; the impacts of each alternative on the matters protected by the controlling provisions of the action and an explanation as to why one alternative is preferred to an other.	The guidance document indicates that one of the most critical aspects of any SEA is the opportunity to evaluate and compare the environmental effects of alternatives in the development of a new policy, plan or program. The comparison should help identify how modifications or changes to the policy, plan or programme can reduce environmental risk.	Article 5(1) contains the obligation to identify, describe and evaluate reasonable alternatives. The likely significant environmental effects of the alternatives should be identified, described and evaluated in a comparable way (information taken from the Guidance document).
Baseline review.	The information requirements for a referral require proponents to describe the current state of the environment (regulation 4.03, schedule 2). The same applies to those following the PER/ EIS route.	The analysis of environmental concerns should be undertaken on an iterative basis throughout the policy development process and be fully integrated into the analysis of each of the options developed.	The environmental report is required to contain an overview of the relevant aspects of the current state of the environment, the environmental characteristics of areas likely to be significantly affected and any existing environmental problems which are relevant to the plan or programme including those relating to areas of importance such as those pursuant to Directives 79/409/EEC and 92/43/EEC (Annex 1 to the directive).
Impact Identification.	Pursuant to regulation 4.03, schedule 2 (preliminary documentation), proponents must describe the nature and extent of likely impacts. The requirements for those proceeding under PER or EIS require proponents to describe the relevant impacts of the project (regulation 5.04, schedule 4).	Ministers expect the SEA to consider the scope and nature of the likely environmental effects, the need for mitigation to reduce or eliminate adverse effects and the likely importance of any adverse environmental effects, taking mitigation into account.	Pursuant to Article 5 and Annex 1, under the relevant national legislation, project proposers will be required to identify, describe and evaluate the likely significant effects on the environment of the plan or programme. Pursuant to Annex 1, proposers should consider effects on biodiversity, population, human health, fauna, flora, soil, water, air, climatic factors, material assets, cultural heritage, landscape and the interrelationship between the factors. The guidance document produced by the EC to assist with the implementation and interpretation of the directive indicates that effects identified should include, secondary, cumulative, synergistic, short, medium and long-term permanent and temporary, positive and negative effects.
Impact Prediction.	Not specifically mentioned, however the requirements for those proceeding under PER or EIS require proponents to include a detailed assessment of the nature of the likely short and long term impacts and provide a statement relating to whether any of the impacts are unknown, unpredictable or irreversible (regulation 5.04, schedule 4).	Departments and Agencies are encouraged to develop their own analytical tools such as checklists; matrices and modelling scenario building and simulation analysis. In assessing environmental effects, the guidance document suggests people consider: frequency and duration; location and magnitude; timing; risk; irreversibility; cumulative nature.	The term "prediction" is not used, however pursuant to article 5 and annex 1, project proposers will be required to evaluate the likely significant effects on the environment of the plan or programme, criteria to assist with a determination of significance is contained in Annex 2 (makes reference to probability and frequency).
Impact Significance.	The requirements for those proceeding under PER or EIS require proponents to include a detailed assessment of the nature of the likely short and long term impacts and provide a statement relating to whether any of the impacts are unknown, unpredictable or irreversible (regulation 5.04, schedule 4). The Department of the Environment and Heritage has produced administrative guidelines on significance in relation to whether, and in what circumstances, some sectoral activity is likely to have a significant impact on a matter of national environmental significance.	Ministers expect the SEA to consider the scope and nature of the likely environmental effects, the need for mitigation to reduce or eliminate adverse effects and the likely importance of any adverse environmental effects, taking mitigation into account.	Pursuant to article 5 and Annex 1 of the directive, project proposers are required to describe the likely significant effects on the environment. Annex 2 of the directive contains a list of criteria to assist with a determination of significance e.g. location, nature, size, probability, duration, frequency.
Impact Mitigation.	The preliminary information regulation (5.03, schedule 3) require proponents to provide details of mitigation techniques to eliminate or reduce relevant impacts. For those proceeding via a PER or EIS, (regulation 5.04), more detailed information is required. The information provided must include: a description and an assessment of the predicted or expected effectiveness of the measures; the statutory or policy basis of the measures; cost of mitigation measures; the name of agency responsible for endorsing or approving each measure.	Ministers expect the SEA to consider the scope and nature of the likely environmental effects, the need for mitigation to reduce or eliminate adverse effects and the likely importance of any adverse environmental effects, taking mitigation into account.	Article 5(1) and annex I contain the obligation to outline the measures envisaged to prevent, reduce and as fully as possible offset any significant adverse effects on the environment of implementing the plan or programme.
Reporting.	The agreement must provide for the preparation of a draft report on the impacts to which the agreement relates and the publication of the draft report for public comment.	The SEA should address the following: scope and nature of potential effects; the need for mitigation or opportunities for enhancement; scope and nature of residual effects; follow up; public and stakeholder concerns.	In accordance with Annex 1, a non technical summary of the information collected together in the course of the assessments should be put together including information relating to the environmental protection objectives (international, community or member state level requirements) which are relevant to the plan or programme and the way those objectives and any environmental considerations have been taken into account during the preparation of the report.
Consultation.	The draft report must be published for a period of at least 28 days.	Departments and Agencies should use, to the fullest extent possible, existing mechanisms to involve the public as appropriate.	In accordance with article 6, the draft plan or programme and environmental report should be made available to the authorities and the public. Member states are required to designate the authorities to be consulted and the public likely to be affected by or having an interest in the decision making process. If the plan or programme is likely to have significant transboundary effects, the member state in whose territory the plan or programme is being prepared shall before its adoption forward a copy of the draft plan or programme and environmental report to the other member state (article 7).
Review/ Decision Making.	The report should be finalised taking into account the comments (if any) received after publication of the draft reports. The agreement should provide for the making of the recommendations by the Minister to the person about the policy, plan or programme, including recommendations for modification of the policy, plan or programme. The plan can be endorsed by the Minister if he or she is satisfied that the report adequately addresses the impacts to which the agreement relates and either recommended modifications of the policy, plan or programme have been made or any modifications having the same effect have been made.	The SEA should contribute to the development of policies, plans and programs on an equal basis with economic or social analysis of each of the options developed for consideration. The environmental considerations should be fully integrated into the analysis of each of the options developed for consideration, and the decision should incorporate the results of the SEA. Departments and Agencies should prepare a public statement of environmental effects when a detailed assessment of environmental effects has been conducted through an SEA. This is designed to assure stakeholders and the public that environmental factors have been appropriately considered when decisions are made.	In accordance with article 8, the environmental report, the opinions expressed pursuant to article 6 and the results of any transboundary consultations shall be taken into account during the preparation of the plan or programme and before its adoption or submission to the legislative procedure. In accordance with article 9, member states shall ensure that when a plan or programme is adopted, the member states consulted under article 7 are informed and the plan or programme as adopted, a statement summarising how environmental considerations have been integrated into the plan or programme and how the opinions and results of consultations entered into have been taken into account, the reasons for choosing the plan or programme and an overview of the measures for monitoring are made available to the public.
Monitoring.	Not mentioned in article 146.	As part of the report, the department or agency should consider the need for follow up measures to monitor environmental effects or to ensure that implementation of the proposal supports the department' or agency's sustainable development goals.	In accordance with article 10, member states are required to monitor the significant environmental effects of the implementation of plans and programmes in order to identify at an early stage unforeseen adverse effects and to be able to undertake appropriate remedial action.
CCS SPECIFIC GAPS: 1. Does EIA allow for future changes in Science/Knowledge?	No indication as to whether caters for changes in knowledge or science.	No.	The EIA is to be conducted using current knowledge and methods of assessment (article 5).
CCS SPECIFIC GAPS: 2. Does SEA cover cumulative impacts?	YES. The Regulations ask developers to identify "cumulative degradation".	Yes.	YES.
CCS SPECIFIC GAPS: 3. Does legislation require use of available guidelines?	Reference to guidelines is not mentioned, however the Act does refer to the Regulations made under the Act. The regulations provide more detail on aspects of an EIA.	NO: Guidelines were issued but they are advisory not prescriptive.	Not explicitly.
CCS SPECIFIC GAPS: 4. Is the any guidance for undertaking an SEA for CCS?	Not at the Federal level, although there are draft guidelines for the regulatory framework for CO2 geosequestration. Some states/ territories are more advanced in their thinking than others- refer to Barrow Island Act of Western Australia.		
Note:		Each department and Agency is responsible for applying SEA to its proposed policies, plans and programmes as appropriate, determining how an assessment should be conducted, performing the assessment and reporting on the findings of the assessment.	

STEPS IN THE SEA PROCESS.	FRANCE. Environment Code (section 2: Articles L122-4 to L122-11) and Urbanisme Code (article L121-10 to L121-15)	GERMANY. Environmental Impact Assessment Act 2001.	JAPAN	NETHERLANDS
Screening.	Article L122-4 states that a set list (see article L121-10 of Code de l'Urbanisme) of plans, schemes, programs and other planning documents should satisfy an environmental assessment. National Security or Civil Protection plans do not fall in that category. Article L122-7 states that with plans should accompanied with an environmental assessment report or a report explaining an environmental assessment was not deemed necessary.	Pursuant to article 16 of the act, when drawing up and amending development plans, a review of expected significant environmental impacts within the meaning of Directive 2001/42/EC (assessment of the effects of certain plans and programmes on the environment) shall be performed. In a regional planning procedure the project's environmental impacts of regional planning significance may be determined, described and assessed in relation to the planning stage reached by the project	The Ministry of the Environment is currently considering implementation of SEA requirements.	Communication with the Netherlands Commission for EIA about current SEA arrangements, indicates that at present the European SEA Directive has not been translated into national Dutch legislation. They currently apply the SEA directive as it stands and where appropriate they apply their own quality checks. The Netherlands do however what they call the "E-test". The test is related to the environmental assessment of new legislation. The test is designed to check whether the legislation has unintended effects, for example undermine the objectives of government policy. Draft legislation has to be assessed against a series of questions, e.g. What are the consequences of the draft legislation: for energy consumption and mobility?; for the consumption and stocks of raw materials?; for waste streams and atmospheric, soil, and surface water emissions?; for the use of available physical space?
Scoping.	Article L122-6 gives the scope of an environmental assessment. Rule R122-20 details what is expected to be included in an environmental assessment.	Pursuant to article 16(3), if an environmental assessment in a procedure pursuant to article 1 and an EIA in a subsequent approval procedure for a project are being implemented, the EIA may be restricted in the subsequent approval procedure to additional or different significant environmental impacts of the project.		(Refer to European Directive).
Analysis of Alternative Options.	Article L122-6 contains the obligation to describe the other envisaged solutions and the reasons why, especially concerning the protection of the environment, this plan or programme was selected.	Unless the proviso in article 16(5) applies, the documents must contain as a minimum: an overview of the principal alternative options investigated and details of the main reasons for selecting the present project with regard to the environmental impacts of the project (article 6).		(Refer to European Directive).
Baseline review.	Rule R122-20 clearly states that an analysis of the initial state and of the expected evolution of the environment should be included in the environmental assessment.	Pursuant to article 16, a review of the expected significant environmental impacts within the meaning of the EC directive should be performed. Under the directive the environmental report is required to contain an overview of the relevant aspects of the current state of the environment, the environmental characteristics of areas likely to be significantly affected and any existing environmental problems which are relevant to the plan or programme including those relating to areas of importance such as those pursuant to Directives 79/409/EEC and 92/43/EEC (Annex 1 to the directive).		(Refer to European Directive).
Impact Identification.	Article L122-6 requires the that the environmental assessment identify all notable effects that the plan or programme might have on the environment. Rule 122-20 states that the effects on health, biological diversity, fauna, flora, soil, water, air, noise, climate, cultural, archaeological and architectural heritage and landscapes should be analysed.	In a regional planning procedure the project's environmental impacts of regional planning significance may be determined, described and assessed in relation to the planning stage reached by the project. In the subsequent approval procedure the requirements of articles 5-8 (steps in the EIA procedure) and article 11 should be dispensed with in so far as these procedural steps have already taken place in the procedure pursuant to paragraph 2 (regional planning procedure- determination of environmental impacts). Unless the aforementioned applies, pursuant to article 6, at the beginning of the procedure during which the environmental impacts are assess, the developer shall present to the competent authority the documents which are of significance for a decision on the environmental impacts of the project. The documents must contain as a minimum: description of the expected significant adverse environmental impacts of the project having regard to the general level of knowledge an generally accepted assessment methods.		(Refer to European Directive).
Impact Prediction.	Article L122-6 states that all effects identified (see above) should be described and evaluated	Unless the proviso contained in article 16(5) applies, the documents must contain an assessment of the impacts having regard to generally accepted assessment methods (article 6). The definitions contained in article 2 indicate that, assessment should take account of direct and indirect on humans, animals and plants; soil, water, air, climate and landscape; cultural heritage and other material assets; and the interactions between the foregoing protected assets.		(Refer to European Directive).
Impact Significance.	Article L122-6 states that all effects identified (see above) should be described and evaluated	Unless the proviso in article 16(5) applies the documents prepared must contain as a minimum: description of the expected significant adverse environmental impacts of the project having regard to the general level of knowledge an generally accepted assessment methods (article 6).		(Refer to European Directive).
Impact Mitigation.	Article L122-6 contains the obligation to describe the measures envisaged to reduce and, as much as possible, offset any significant adverse effects on the environment of implementing the plan or programme.	Unless the proviso in article 16(5) applies at the beginning of the EIA procedure during which the environmental impacts are assessed, the people responsible shall present to the competent authority the documents which are of significance for a decision on the environmental impacts of the project. The documents must contain as a minimum: a description of the measures which will be taken to avoid, reduce or so far as possible compensate for any significant adverse environmental impacts and the substitute measures in the case of priority encroachments on nature and landscape for which no compensation is possible.(article 6).		(Refer to European Directive).
Reporting.	Article L122-6 states that the environmental report shall contain all reasonable information, bearing in mind the status of knowledge and techniques at the time of the analysis, its content and degree of accuracy, and if applicable, the existence of other documents or plans for the same zone, or other environmental assessments planned for later. Article L122-7 states that the plan or programme should be transmitted to the competent authority with the relevant environmental report, or the reason why an environmental report was not deemed necessary.	Unless the proviso in article 16(5) applies the documents must also include a non-technical summary of the information in the preceding sections and in so far as they are necessary for the EIA: a description of the main features of the technical processes used; a description of the type and extent of emissions, waste, wastewater, use and design of water, soil, nature and landscape and details of other consequences of the project that might result in significant adverse environmental impacts; and an indication of any difficulties encountered in compiling the information e.g. technical gaps or lack of knowledge.		(Refer to European Directive).
Consultation.	Article L122-7 requires the plan with relevant environmental report to be presented to the competent authority. Article L122-8 states that the environmental report is then made available to the public. Article L122-9 requires any plan or programme with potential effect on the environment of another member of the European Community to be communicated to that State for information and consultation. This article also says that in the case when another member state consults France over a plan which might adverse effects on its environment, it can be decided to make the consultation available to the public.	Unless the proviso in article 16(5) applies, consultation is required. Articles 7, 8, 9 and 10 provide for public and other authority consultation and review of documentation (including where necessary transboundary consultations) prior to a decision being taken.		(Refer to European Directive).
Review/ Decision Making.	Article L122-10 requires that after plan has been approved, the public is informed, and that the environmentally competent authority and the other member state be advised. All are given the following info: the plan or document, how the environmental report (according to L122-6) was taken into account, the reasons why the plan was approved, and the measures planned to evaluate/monitor the consequences of the implementation of the plan on the environment.	Pursuant to article 12, the competent authority shall assess the environmental impacts of the project on the basis of a summary description that must be provided pursuant to article 11 and shall take this assessment into account when deciding on the admissibility of the project with regard to effective preventative environmental protection in accordance with the applicable laws. project may need to be approved by both federal authorities and regional "Land" authorities, if so the "Lander" shall designate a lead authority to be responsible for at least the tasks pursuant to articles 3, 5, 8, 9 and 11.		(Refer to European Directive).
Monitoring.	Article L122-10 says that the measures planned to evaluate/monitor the consequences of the implementation of the plan on the environment should be communicated.	Does not appear to be mentioned.		(Refer to European Directive).
CCS SPECIFIC GAPS: 1. Does EIA allow for future changes in Science/Knowledge?	The SEA is to be conducted using current knowledge and methods of assessment (article L122-6).	Possibly- article 16 says that an EIA is to be conducted in line with the European Directive.	N/A.	(Refer to European Directive).
CCS SPECIFIC GAPS: 2. Does SEA cover cumulative impacts?	yes, article L122-6 mentions that knowledge of other plans or programmes in the same area should be included in the environmental report.	NO: all the Act says is the "expected significant adverse environmental impacts".	N/A.	(Refer to European Directive).
CCS SPECIFIC GAPS: 3. Does legislation require use of available guidelines?	Yes, guidelines are rules to follow , e.g. R122-20, etc	No.	N/A.	(Refer to European Directive).
CCS SPECIFIC GAPS: 4. Is the any guidance for undertaking an SEA for CCS?	No		N/A.	

STEPS IN THE SEA PROCESS.	Norway	IAIA (best practice)	IFC/ World Bank.	UK The Environmental Assessment of Plans and Programmes Regulations 2004 (SI 1633/04).
Screening.	Apparently there are no guidelines for SEA in Norway. Within the Oil industry Regional EIAs are performed both by the operators themselves (every 5 years) and by the Government before new acreage is opened for licensing. The latter appears to be the closest to SEA in Norway. No specific methodology exist but there are many methods and models used for specific tasks of the impact assessment work. Currently Norway are working with Ecosystem based Management Plans for oceans and the ground work is a set of sector wise EIAs summarised in a type of SEA. Available in Norwegian only. No specific guidelines or methodology used.	To date the IAIA do not appear to have issued best practice guidance relating to SEA however they have issued SEA performance criteria that is designed to provide guidance on what a good quality SEA process should be, for example it should be integrated, sustainability led, participative and iterative. In late 2005 they held a conference to highlight international experience and perspectives on SEA.	[illegible]	[illegible]
Scoping.				[illegible]
Analysis of Alternative Options.				[illegible]
Baseline review.				[illegible]
Impact Identification.				[illegible]
Impact Prediction.				Schedule 1 contains criteria to assist with determination of the likely significance of effects on the environment. Criteria include: characteristics of the plan or programme and characteristics of the effects and of the area likely to be affected. According to the guidance document, prediction of the effects involves describing the changes in terms of their magnitude, geographical scale, time period over which they will occur etc. Predictions do not have to be expressed in quantitative terms. Qualitative data supported by evidence is acceptable for an SEA or sustainability appraisal. The report should document any uncertainties, assumptions or limitations in the information underlying the predictions.
Impact Significance.				Schedule 1 contains criteria to assist with determination of the likely significance of effects on the environment. Criteria include: characteristics of the plan or programme and characteristics of the effects and of the area likely to be affected.
Impact Mitigation.				Pursuant to schedule 2, the report should document the measures envisaged to prevent, reduce and as fully as possible offset any significant adverse effects on the environment of implementing the plan or programme.
Reporting.				Pursuant to schedule 2, the report should contain a non technical summary of the information provided under paragraphs 1-9 of schedule 2.
Consultation.				Pursuant to article 13, every draft plan or programme with an environmental report shall be made available for the purposes of consultation in accordance with the regulation. In accordance with regulation 14, transboundary consultations should take place if the plan or programme is likely to have significant transboundary environmental effects. Pursuant to regulation 4, each of the following bodies shall be a consultation body: the Countryside Agency; the Historic Buildings and Monuments Commission for England; English Nature; Environment Agency. In Scotland: Scottish Ministers; SEPA; Scottish Natural Heritage.
Review/ Decision Making.				After consultation responses have been received, the European directive requires them to be "taken into account" during the preparation of the evolving plan. Once a decision has been taken, a copy of the plan or programme with the accompanying environmental report should be made available for inspection and they should inform the consultation bodies, public consulters and Secretary of State (regulation 16). The authority should make it clear how environmental considerations have been integrated into the plan or programme; how the environmental report has been taken into account; how opinions and consultations expressed have been taken into account; the reasons for choosing the plan or programme; the measures to be taken to monitor the effects.
Monitoring.				Pursuant to article 17, the responsible authority shall monitor the significant environmental effects of the implementation of each plan or programme with the purpose of identifying unforeseen adverse effects at an early stage and being able to take appropriate remedial action.
CCS SPECIFIC GAPS: 1. Does EIA allow for future changes in Science/Knowledge?	N/A.	N/A.	N/A.	POSSIBLY: The Report should take account of "current knowledge and methods of assessment".
CCS SPECIFIC GAPS: 2. Does SEA cover cumulative impacts?	N/A.	N/A.	N/A.	YES.
CCS SPECIFIC GAPS: 3. Does legislation require use of available guidelines?	N/A.	N/A.	N/A.	NO.
CCS SPECIFIC GAPS: 4. Is the any guidance for undertaking an SEA for CCS?	N/A.	N/A.	N/A.	

STEPS IN THE SEA PROCESS.	UNECE. Protocol on Strategic Environmental Assessment to the Convention on EIA in a Transboundary Context.	USA. (National Environmental Policy Act 1969, as implemented by Executive orders 11514 & 11991 and the Council on Environmental Quality Regulations 1978).	Combined Best.
Screening.	[illegible]	The National Environmental Policy Act 1969 requires an EIA for "major Federal Actions significantly affecting the quality of the human environment" (Section 102). The CEQ regulations define "major Federal actions" as including projects and programmes, rules, regulations, plans, policies or procedures and legislative proposals advanced by Federal Agencies (1508.8). This means that in the USA, SEA procedures are not distinguished from project EIA procedures. Refer to the EIA process for information pertaining to each phase in the SEA process.	Screen to determine whether or not the policy, plan or programme requires an SEA. Consultation with interested parties, governments or authorities as required.
Scoping.	[illegible]	Refer to the EIA process for information pertaining to each phase in the SEA process.	The aim of the scoping process is to determine the items and issues to be addressed in the SEA (terms of reference). The people responsible for the plan, policy or programme should outline the methods to be used in the course of the SEA. Interested and affected parties should be given the opportunity to comment on the scope of the SEA.
Analysis of Alternative Options.	[illegible]	Refer to the EIA process for information pertaining to each phase in the SEA process.	The people responsible should include a description of the alternatives to the proposed project. The description should include an assessment of the potential impacts and potential mitigation. The option of no action should be considered.
Baseline review.	[illegible]	Refer to the EIA process for information pertaining to each phase in the SEA process.	The objective of the baseline review is to describe the state of the environment as it is prior to commencement of project operations. The review should describe the flora & fauna; water (aquifers; water courses; shore lines; existing discharges); soil (geology; geomorphology; including seismic characteristics); air (quality; climatic factors); architectural, historic and cultural heritage. The SEA should be an iterative process throughout the life of the policy or plan to ensure that changes in environmental conditions are taken account of.
Impact Identification.	[illegible]	Refer to the EIA process for information pertaining to each phase in the SEA process.	The people responsible should identify all aspects of the project that could impact upon; environmental or biophysical factors; socio-economic factors e.g. health, culture, lifestyle, gender. Impacts should include short- medium and long-term effects; positive and negative; primary and secondary; cumulative; permanent and temporary; escalation/ domino effect; reversible and irreversible; and inter-relationships between them.
Impact Prediction.	The term "prediction" is not used, however pursuant to article 7, project proposers will be required to "evaluate" the likely significant effects on the environment of the plan or programme.	Refer to the EIA process for information pertaining to each phase in the SEA process.	The impacts identified in the preceding stage should be quantified via qualitative, quantitative and semi- quantitative techniques. It should include frequency, duration, magnitude, risk etc.
Impact Significance.	Pursuant to article 7 and Annex III of the protocol, project proposers are required to describe the likely significant effects on the environment. Annex III contains a list of criteria to assist with a determination of significance e.g. location, nature, size, probability, duration, frequency.	Refer to the EIA process for information pertaining to each phase in the SEA process.	In determining the significance of activities, the responsible people should consider the size of the project; location (near SSSI's); and the nature of the effects. Impacts should be screened and prioritised accordingly.
Impact Mitigation.	Article 7(2) and annex IV contain the obligation to outline the measures envisaged to prevent, reduce and as fully as possible offset any significant adverse effects on the environment of implementing the plan or programme.	Refer to the EIA process for information pertaining to each phase in the SEA process.	The people responsible should provide a description of the measures which will be taken to avoid; reduce; or remedy significant adverse effects. The description should include an overview of the predicted expected cost effectiveness of the measures; the statutory or policy basis of the measures; cost of mitigation.
Reporting.	In accordance with article 7 and annex IV, a non technical summary of the information collected should be drafted for inclusion in the report. Each party is required to ensure that the environmental reports are of sufficient quality to meet the requirements of the protocol as stated in annex IV, taking into account current knowledge and methods of assessment; the contents and level of detail of the plan or programme and its stage in the decision making process; the interests of the public; the information needs of the decision making body.	Refer to the EIA process for information pertaining to each phase in the SEA process.	The people responsible should prepare a draft SEA report containing a non-technical summary of the aforementioned information.
Consultation.	Pursuant to articles 3, 8 and 9, each party to the convention is required to provide for appropriate recognition of and support to associations, organisations or groups promoting environmental (including health) protection in the context of this protocol. Participation should be timely and effective. The draft plan or programme and the environmental report should be made available for consultation. Where a party of origin considers that the implementation of a plan or programme is likely to have significant transboundary effects or where a party likely to be significantly affected so requests, the party of origin shall as early as possible before the adoption of the plan or programme notify the affected party. The notification should contain the draft plan or programme and the environmental report. Consultations should take place in relation to the effects and the measures envisaged to prevent, reduce or mitigate adverse effects.	Refer to the EIA process for information pertaining to each phase in the SEA process.	Consultation with interested and affected parties on the basis of the draft documentation. The comments should be fed back to the people responsible so that the SEA can be altered accordingly.
Review/ Decision Making.	Pursuant to article 11, each party shall ensure that when a plan or programme is adopted due account is taken of the conclusions of the environmental report; the measures to mitigate, prevent or reduce the adverse effects; the comments received in accordance with articles 8, 9 & 10. When a plan or programme is adopted, each party shall inform the public, the authorities referred to in article 9(1) and the parties consulted according to article 10 are informed. They should be provide with the plan or programme, a statement summarising how the environmental (including health) considerations have been integrated into it, how the comments received have been taken into account and the reasons for adopting it in light of the reasonable alternatives considered.	Refer to the EIA process for information pertaining to each phase in the SEA process.	The responsible authority should review the final documentation and make a decision in light of the report and consultation. Conditions may be attached to the approval e.g. relating to mitigation measures to be taken.
Monitoring.	Pursuant to article 12, each party shall monitor the significant effects of the implementation of the plans or programmes adopted under article 11 in order to identify at an early stage, unforeseen adverse effects and to be able to undertake appropriate remedial action.	Refer to the EIA process for information pertaining to each phase in the SEA process.	The people responsible should engage in monitoring as per the plan. The aim of monitoring is to assess the effectiveness of the mitigation measures and to identify unforeseen effects. The responsible authority should ensure that any conditions attached to the approval are being met.
CCS SPECIFIC GAPS: 1. Does EIA allow for future changes in Science/Knowledge?	POSSIBLY: The Report should take account of "current knowledge and methods of assessment".	No indication as to whether caters for changes in knowledge or science.	
CCS SPECIFIC GAPS: 2. Does SEA cover cumulative impacts?	YES.	NO	
CCS SPECIFIC GAPS: 3. Does legislation require use of available guidelines?	NO- whilst guidance is produced it is not mandatory to use it.	No.	
CCS SPECIFIC GAPS: 4. Is the any guidance for undertaking an SEA for CCS?			

(green) Indicates steps that would add value to a new EIA for CCS.

(yellow) Gaps in the regulations.

NOTE. DNV are environmental consultants, not environmental lawyers; this document does not represent a legal review, rather a general review of the frameworks.

APPENDIX B

Projects covered by EIA Legislation that may include CCS

This Appendix considers the types of projects currently captured by EIA legislation in the countries within the scope of the study. Obviously, CCS projects are not currently specifically mentioned because the technique is relatively new. However, CCS projects may be captured under other areas identified in the EIA legislation, as highlighted below.

It is found that in some cases CCS projects may be captured by current legislation. For example, in the EU, a new proposed development involving CCS from a power station may be captured by existing EIA legislation because the Directive requires "…any change or extension of projects listed in Annex I or Annex II, already authorized, executed or in the process of being executed, which may have significant adverse effects on the environment". Because the new proposed development would require significant extension to the power station, the CCS development would be captured by the framework, and require consideration for an EIA.

However, this may not be the case for all proposed CCS developments, as there are many different types of CCS that may not require change or extension of Projects listed in Annex I/II.

Similarly, there is an argument that if the definition of oil or gas is amended then CCS projects would be captured by EIA legislation in many cases.

It is suggested that the simplest mechanism to ensure capture of a CCS development may be to amend EIA legislation in national countries such that CCS projects are required to be subject to an EIA.

Developments that currently require an EIA under existing legislation, and may cover CCS developments, are discussed below.

Note that this document is not intended to be a legal interpretation of the EIA legislation.

1. AUSTRALIA

In relation to the activities covered by the act, the act nor the regulations contain a list of activities similar to the list contained in the EU directive, instead the EPBC Act protects seven matters of national environmental significance:

- World Heritage properties
- National Heritage places;
- Ramsar wetlands
- nationally threatened species and communities
- migratory species protected under international agreements
- the Commonwealth marine environment
- nuclear actions

Examples of referrals since 2001 include: water transport; waste management and use; urban and commercial development; mining; science, research and investigations.

2. GERMANY

Under the Act, a project is defined as "..projects involving alteration including expansion of the location or nature of an installation". Theoretically an alteration of a power plant to include carbon capture technology would be covered under this wording.

The projects covered by the Act are contained in Annex 1, the list includes:
- Construction and operation of a pipeline system not falling under number 19.3 or, as an energy installation within the meaning of the Energy Management Act [*Energiewirtschaftsgesetz*], under number 19.2, for the transport of non-liquefied gases, with the exception of systems which do not extend outside a factory site, having a length of more than 40 km and a pipeline diameter of more than 800 mm; a length of more than 40 km and a pipeline diameter of 300 mm to 800 mm; a length of 5 km to 40 km and a pipeline diameter of more than 300 mm,

- Construction and operation of a pipeline system for the transport of substances within the meaning of Art. 3a of the Chemicals Act *[Chemikaliengesetz]*, insofar as it does not fall under one of numbers 19.2 to 19.5, and excluding wastewater pipelines and installations which do not extend outside a factory site or which are accessories to a facility for the storage of such substances, having specified lengths and diameters.

3. IFC

The operational policy does not contain a list of projects covered as such, the policy simply states that the IFC, requires environmental assessment (EA) of projects proposed for IFC financing to help ensure that they are environmentally sound and sustainable, and thus to improve decision making.

4. JAPAN

Article 1: In order to achieve these purposes, this law sets forth procedures and contains other provisions designed to clearly define the responsibilities of the government regarding EIA and to ensure that such assessments are conducted properly and smoothly with respect to large-scale projects that could have a serious impact on the environment.
Article 2: In this law, "Class-1 Project" shall mean a large-scale project (in this and the following paragraph, scale shall mean the measurable aspects of a project, such as the land area to be altered and the size of any structure(s) to be built).

5. NORWAY

Projects that require a permit pursuant to sector legislation:

b) industrial installations for transport of gas with a pipeline more than 20 km in length and a pipe more than 15 inches in diameter

6. UK

Schedule 1: Projects Requiring EIA:
16. Pipelines for the transport of gas, oil or chemicals with a diameter of more than 800 millimetres and a length of more than 40 kilometres.

Schedule 2: Projects that may require an EIA.
(c) Construction of inter-modal trans-shipment facilities and of inter-modal terminals (unless included in Schedule 1);

b) Installations for the disposal of waste (unless included in Schedule 1); the threshold for triggering an EIA is:

(ii) the area of the development exceeds 0.5 hectare; or

(iii) the installation is to be sited within 100 metres of any controlled waters.

and

13. (a) Any change to or extension of development of a description listed in Schedule 1 or in paragraphs 1 to 12 of Column 1 of this table, where that development is already authorised, executed or in the process of being executed, and the change or extension may have significant adverse effects on the environment

7. USA

Neither NEPA nor the CEQ regulations contains a list of activities that specifically require an EIA, instead they provide general guidance in sec1502.4 highlighted below and define activities that are specifically excluded from having to undergo and EIA.

Sec. 1502.4 Major Federal actions requiring the preparation of environmental impact statements.

(a) Agencies shall make sure the proposal which is the subject of an environmental impact statement is properly defined. Agencies shall use the criteria for scope (Sec. 1508.25) to determine which proposal(s) shall be the subject of a particular statement. Proposals or parts of proposals which are related to each other closely enough to be, in effect, a single course of action shall be evaluated in a single impact statement.

(b) Environmental impact statements may be prepared, and are sometimes required, for broad Federal actions such as the adoption of new agency programs or regulations (Sec. 1508.18). Agencies shall prepare statements on broad actions so that they are relevant to policy and are timed to coincide with meaningful points in agency planning and decision making.

(c) When preparing statements on broad actions (including proposals by more than one agency), agencies may find it useful to evaluate the proposal(s) in one of the following ways:

1. Geographically, including actions occurring in the same general location, such as body of water, region, or metropolitan area.
2. Generically, including actions which have relevant similarities, such as common timing, impacts, alternatives, methods of implementation, media, or subject matter.
3. By stage of technological development including federal or federally assisted research, development or demonstration programs for new technologies which, if applied, could significantly affect the quality of the human environment. Statements shall be prepared on such programs and shall be available before the program has reached a stage of investment or commitment to implementation likely to determine subsequent development or restrict later alternatives.

Sec. 1508.4 Categorical exclusion.

"Categorical exclusion" means a category of actions which do not individually or cumulatively have a significant effect on the human environment and which have been found to have no such effect in procedures adopted by a Federal agency in implementation of these regulations (Sec. 1507.3) and for which, therefore, neither an environmental assessment nor an environmental impact statement is required. An agency may decide in its procedures or otherwise, to prepare environmental assessments for the reasons stated in Sec. 1508.9 even though it is not required to do so. Any procedures under this section shall provide for extraordinary circumstances in which a normally excluded action may have a significant environmental effect.

8. UNECE

Projects requiring an EIA include:
8. Large-diameter pipelines for the transport of oil, gas or chemicals.

9. IAIA

The best practice guidelines do not specify which activities should be covered by an EIA.

10. CANADA

The following activities require an EIA under the Canadian Regulations:
PART II
OIL AND GAS PROJECTS:
15. Physical activities relating to the abandonment of the operation of a pipeline that requires leave under paragraph 74(1)(*d*) of the *National Energy Board Act*.
PART VI
WASTE MANAGEMENT
40. The dumping of any substance for which a permit is required under Part VI of the *Canadian Environmental Protection Act*.
PART X
NORTHERN PROJECTS
68. Physical activities relating to the use of waters or the deposit of waste that require a licence under subsection 14(1) of the *Yukon Waters Act* or that are the subject of a renewal of or amendment to a licence under paragraph 18(1)(*a*) or (*b*), or physical activities relating to a cancellation of a licence under paragraph 18(1)(*c*) of that Act.
69. Physical activities relating to the use of waters or the deposit of waste that require a licence under subsection 14(1) of the *Northwest Territories Waters Act* or that are the subject of a renewal of or amendment to a licence under paragraph 18(1)(*a*) or (*b*), or physical activities relating to a cancellation of a licence under paragraph 18(1)(*c*) of that Act.

11. EUROPEAN EIA DIRECTIVE

Annex 1 gives an overview of the projects requiring an EIA, but also refers to lifecycle issues.
2. Thermal power stations and other combustion installations with a heat output of 300 megawatts or more, and nuclear power stations and other nuclear reactors including the dismantling or decommissioning of such power stations or reactors (*).
16. Pipelines for the transport of gas, oil or chemicals with a diameter of more than 800 mm and a length of more than 40 km.
21. Installations for storage of petroleum, petrochemical, or chemical products with a capacity of 200 000 tonnes or more.
Subject to Annex II, the following may require an EIA:
(i) Oil and gas pipeline installations (projects not included in Annex I);
13. - Any change or extension of projects listed in Annex I or Annex II, already authorized, executed or in the process of being executed, which may have significant adverse effects on the environment;
- Projects in Annex I, undertaken exclusively or mainly for the development and testing of new methods or products and not used for more than two years.

12. NETHERLANDS

Pursuant to the Environmental regulations, the following projects require an EIA:
2) The construction of a pipeline for the transportation of gas, oil or chemicals in cases where the activity relates to a pipeline with a diameter greater than 800 millimetres and a length of more than 40 kilometres.

3) The construction of an industrial site in cases where the activity relates to an industrial site with an area of 150 hectares or more.

The legislation also covers extension of installations covered in the annexes.

13. FRANCE

Article L122-1 of Environmental Code states that town and country planning works or projects undertaken by a public authority or requiring authorisation or approval, along with the planning documents, must respect environmental concerns. Studies carried out prior to those works or projects, which may harm natural environment by their dimensions or by their impact, must include an impact study.

Articles R122-4 to R122-8 gives lists of projects that are exempted of carrying out an EIA.

APPENDIX C

Developments covered by SEA legislation that may include CCS

This Appendix considers the types of projects currently captured by strategic environmental assessment (SEA) legislation in the countries within the scope of the study. CCS projects are not currently specifically mentioned because the CCS technique is relatively new. However, CCS projects may be captured under other areas identified in current SEA legislation, as highlighted below.

It is found that in some cases CCS projects may be captured by current legislation. For example, in the EU (and the Netherlands which currently applies the directive as it stands), a new proposed development involving CCS from a power station may be captured by the existing SEA framework because the Directive requires plans or programs which are prepared for industry and which set the framework for future development consent of projects under the EIA directive to be subject to an environmental assessment. Therefore theoretically if the EU decided that a programme of CCS projects was going to be instituted, an environmental assessment would be carried out of the likely sequestration area (e.g. North Sea) in order to identify in advance the areas where applications for development consent for individual CCS projects would or would not be considered. In relation to the UK and UNECE Convention the same conclusion applies because the text of the British legislation and UNECE Convention broadly reflects that of the EU directive.

In relation to the USA it is possible that CCS projects would be covered under section 1502.4 which requires agencies when considering statements on broad actions to evaluate proposals in a number of ways including geographically. Whilst the wording of the text is very broad, theoretically if an agency was considering CCS they would be required to consider the proposal in relation to the locations being considered hence some consideration of geology etc would be required before the proposal was approved.

In relation to Australia, Canada and Germany, the situation is unclear because the text of the relevant legislation is too broad to draw conclusions.

With respect to Norway, Japan, the IAIA and IFC, no conclusions could be drawn because none appear to currently have any legislation or guidance framework.

Areas of current SEA legislation that may cover CCS developments are discussed below.

Note that this document is not intended to be a legal interpretation of the SEA legislation.

1. IAIA

- None listed.

2. UNECE

SEA shall be carried out for plans and programmes which are prepared for agriculture, forestry, fisheries, energy, industry including mining, transport, regional development, waste management, water management, telecommunications, tourism, town and country planning or land use, and which set the framework for future development consent for projects listed in annex I and any other project listed in annex II that requires an EIA under national legislation.

Projects include:

- Industrial applications for carrying gas, steam and hot water.
- Deep drillings, with the exception of drillings for investigating the stability of soil.
- Pipelines for transport of gas or oil, as far as not included in Annex I.
- Pipelines for transport of chemicals with a diameter of more than 800 mm and a length of 40km.
- Waste disposal installations (including landfill) as far as not included in annex I.

3. UK

The regulation itself does not contain a list like the UNECE document, however some guidance is given on the type of plans / programmes etc that might be covered:

The requirement for environmental assessment applies, in particular, to any plan or programme prepared for agriculture, forestry, fisheries, energy, industry, transport, waste management, water management, telecommunications, tourism, town and country planning or land use, which sets the framework for future development consent of projects listed in Annex I or II to Council Directive 85/337/EEC on the assessment of the effects of certain public and private projects on the environment, as amended by Council Directive 97/11/EC; and to any plan or programme which, in view of the likely effect on sites, has been determined to require an assessment pursuant to Article 6 or 7 of Council Directive 92/43/EEC on the conservation of natural habitats and of wild flora and fauna, as last amended by Council Directive 97/62/EC (regulation 5(1) to (3); Article 3.2 of the Directive).

9.—(1) The responsible authority shall determine whether or not a plan, programme or modification of a description referred to in—

(a) paragraph (4)(a) and (b) of regulation 5;

> ((4) Subject to paragraph (5) and regulation 7, where— (a) the first formal preparatory act of a plan or programme, other than a plan or programme of the description set out in paragraph (2) or (3), is on or after 21st July 2004;
> (b) the plan or programme sets the framework for future development consent of projects;

(b) paragraph (6)(a) of that regulation; or

(c) paragraph (6)(b) of that regulation, is likely to have significant environmental effects.

> (6) An environmental assessment need not be carried out—
> (a) for a plan or programme of the description set out in paragraph (2) or (3) which determines the use of a small area at local level; or
> (b) for a minor modification to a plan or programme of the description set out in either of those paragraphs

(2) Before making a determination under paragraph (1) the responsible authority shall—

> (a) take into account the criteria specified in Schedule 1 to these Regulations; and
> (b) consult the consultation bodies.

(3) Where the responsible authority determines that the plan, programme or modification is unlikely to have significant environmental effects (and, accordingly, does not require an environmental assessment), it shall prepare a statement of its reasons for the determination.

SCHEDULE 1 Regulations 9(2)(a) and 10(4)(a):
Criteria for determining the likely significance of effects on the environment:

1. The characteristics of plans and programmes, having regard, in particular, to—
(a) the degree to which the plan or programme sets a framework for projects and other activities, either with regard to the location, nature, size and operating conditions or by allocating resources;
(b) the degree to which the plan or programme influences other plans and programmes including those in a hierarchy;
(c) the relevance of the plan or programme for the integration of environmental considerations in particular with a view to promoting sustainable development;
(d) environmental problems relevant to the plan or programme; and
(e) the relevance of the plan or programme for the implementation of Community legislation on the environment (for example, plans and programmes linked to waste management or water protection).

2. Characteristics of the effects and of the area likely to be affected, having regard in particular to:
(a) the probability, duration, frequency and reversibility of the effects;
(b) the cumulative nature of the effects;
(c) the transboundary nature of the effects;
(d) the risks to human health or the environment (for example, due to accidents);
(e) the magnitude and spatial extent of the effects (geographical area and size of the population likely to be affected);
(f) the value and vulnerability of the area likely to be affected due to—
(i) special natural characteristics or cultural heritage;
(ii) exceeded environmental quality standards or limit values; or
(iii) intensive land-use; and
(g) the effects on areas or landscapes which have a recognised national, Community or international protection status.

4. USA

Neither NEPA nor the CEQ regulations contains a list of activities that specifically require an SEA or EIA, instead they provide general guidance in sec1502.4 highlighted below and define activities that are specifically excluded from having to undergo environmental assessment.

Sec. 1502.4 Major Federal actions requiring the preparation of EIA:

> (a) Agencies shall make sure the proposal which is the subject of an environmental impact statement is properly defined. Agencies shall use the criteria for scope (Sec. 1508.25) to determine which proposal(s) shall be the subject of a particular statement. Proposals or parts of proposals which are related to each other closely enough to be, in effect, a single course of action shall be evaluated in a single impact statement.
> (b) Environmental impact statements may be prepared, and are sometimes required, for broad Federal actions such as the adoption of new agency programs or regulations (Sec. 1508.18). Agencies shall prepare statements on broad actions so that they are relevant to policy and are timed to coincide with meaningful points in agency planning and decision making.
> (c) When preparing statements on broad actions (including proposals by more than one agency), agencies may find it useful to evaluate the proposal(s) in one of the following ways:
>
> 1. Geographically, including actions occurring in the same general location, such as body of water, region, or metropolitan area.

2. Generically, including actions which have relevant similarities, such as common timing, impacts, alternatives, methods of implementation, media, or subject matter.
3. By stage of technological development including federal or federally assisted research, development or demonstration programs for new technologies which, if applied, could significantly affect the quality of the human environment. Statements shall be prepared on such programs and shall be available before the program has reached a stage of investment or commitment to implementation likely to determine subsequent development or restrict later alternatives.

Sec. 1508.4 Categorical exclusion.
"Categorical exclusion" means a category of actions which do not individually or cumulatively have a significant effect on the human environment and which have been found to have no such effect in procedures adopted by a Federal agency in implementation of these regulations (Sec. 1507.3) and for which, therefore, neither an environmental assessment nor an environmental impact statement is required. An agency may decide in its procedures or otherwise, to prepare environmental assessments for the reasons stated in Sec. 1508.9 even though it is not required to do so. Any procedures under this section shall provide for extraordinary circumstances in which a normally excluded action may have a significant environmental effect.

5. GERMANY

Pursuant to article 16 of the act, when drawing up and amending development plans, a review of expected significant environmental impacts within the meaning of Directive 2001/42/EC (assessment of the effects of certain plans and programmes on the environment) shall be performed. In a regional planning procedure the project's environmental impacts of regional planning significance may be determined, described and assessed in relation to the planning stage reached by the project.

Whilst the Act identifies a list of activities that require an EIA (listed in annex 1), article 16 (SEA article below) does not refer to annex 1- therefore it is unclear to DNV as to whether the list of activities applies to SEA plans and programmes.

Article 16 Development plans, regional planning procedure and approval procedure

(1) When drawing up and amending development plans, a review of expected significant environmental impacts within the meaning of Directive 2001/42/EC of the European Parliament and of the Council of 27 June 2001 on the assessment of the effects of certain plans and programmes on the environment (Official Journal EC No. L 197 p. 30) (environmental assessment) shall be performed.
(2) In a regional planning procedure the project’s environmental impacts of regional planning significance may be determined, described and assessed in relation to the planning stage reached by the project.
(3) If an environmental assessment in a procedure pursuant to Article 1 and an EIA in a subsequent approval procedure for a project are being implemented, the EIA may be restricted in the subsequent approval procedure to additional or different significant environmental impacts of the project.
(4) Pursuant to Art. 12 the competent authority shall in the subsequent approval procedure for a project take account in its decision on the admissibility of the project of the project’s

environmental impacts determined, described and assessed in the procedure pursuant to paragraph 2.
(5) In the subsequent approval procedure the requirements of Art. 5 to 8 and Art. 11 should be dispensed with in relation to the environmental impacts determined and described in the procedure pursuant to paragraph 2, insofar as these procedural steps have already taken place in 15 the procedure pursuant to paragraph 2. Hearing of the public pursuant to Art. 9 paragraph 1 and Art. 9a and assessment of environmental impacts pursuant to Art. 12 should be restricted to additional or different significant environmental impacts, insofar as the public was involved in the procedure pursuant to paragraph 2 in accordance with the provisions of Art. 9 paragraph 3.

6. EU

The directive itself does not contain a list of activities requiring an SEA as found in the UNECE document, however article 3 refers to a broad range of industries that need to be considered and refers to the activities covered by the EIA directive:

2. Subject to paragraph 3, an environmental assessment shall be carried out for all plans and programmes,
(a) which are prepared for agriculture, forestry, fisheries, energy, industry, transport, waste management, water management, telecommunications, tourism, town and country planning or land use and which set the framework for future development consent of projects listed in Annexes I and II to Directive 85/337/EEC, or
(b) which, in view of the likely effect on sites, have been determined to require an assessment pursuant to Article 6 or 7 of Directive 92/43/EEC.
3. Plans and programmes referred to in paragraph 2 which determine the use of small areas at local level and minor modifications to plans and programmes referred to in paragraph 2 shall require an environmental assessment only where the Member States determine that they are likely to have significant environmental effects.
4. Member States shall determine whether plans and programmes, other than those referred to in paragraph 2, which set the framework for future development consent of projects, are likely to have significant environmental effects.
5. Member States shall determine whether plans or programmes referred to in paragraphs 3 and 4 are likely to have significant environmental effects either through case-by-case examination or by specifying types of plans and programmes or by combining both approaches. For this purpose Member States shall in all cases take into account relevant criteria set out in Annex II, in order to ensure that plans and programmes with likely significant effects on the environment are covered by this Directive.

7. JAPAN

Currently there are no SEA regulations in Japan.

8. NETHERLANDS

At present the European SEA Directive has not been translated into national Dutch legislation. They currently apply the SEA directive as it stands and where appropriate they apply their own quality checks therefore refer to the European Directive summary above.

9. NORWAY

There are understood to be no guidelines for SEA in Norway. Within the Oil industry Regional EIAs are performed both by the operators (every 5 years) and by Government before new acreage is opened for licensing, and this is understood to be the closest to SEA in Norway.

10. AUSTRALIA

Section 146 includes explicit provision for discretionary strategic assessment of particular actions that may be carried out under a proposed policy, programme or plan. The Minister may agree in writing with a person responsible for the adoption or implementation of a policy, plan or programme that an assessment be made of the impacts of actions under the policy, plan or programme on a matter protected by a provision of Part 3. The agreement may also provide for the assessment of other certain and likely impacts of actions under the policy, plan or programme if: the actions are to be taken in a State or self-governing territory; and the appropriate Minister of the State or Territory has asked the Minister administering section 146 to ensure that the assessment deal with those impacts to help the state and the actions are to be taken by any person for the purposes of trade or commerce between Australia and another country or are actions whose regulation is appropriate and adapted to give effect to Australia's obligation under an agreement with one or more countries.

11. WORLD BANK/ IFC

Contact with the IFC and World Bank revealed that "SEA is non-mandatory for assessing requests for financial assistance, unlike EIA under operational policy 4.01. However they stated that SEA could be applied to satisfy the environmental assessment requirements of a particular strategy, policy, plan or programme that are likely to have significant sectoral or regional environmental impacts. Environmental assessment is mandatory in these cases under operational policy 4.01.

SEA could be used under operational policy 8.60 on development policy lending. The policy requires the Bank to determine whether specific country policies supported by policy lending operation are likely to have significant effects on the country's environments. For policies with significant effects, an assessment is required by bank staff of the country's systems for reducing adverse effects and enhancing positive effects, drawing on relevant country level or sectoral environmental analysis. As a sectoral environmental analysis is a type of SEA, this policy suggests that the Bank should draw information as needed from existing SEA's. In addition, the assessment of the significance of effects and country capacity to manage them that need to be carried out under this policy could be satisfied by applying SEA". Dr Fernando Loayza, Snr SEA Specialist, World Bank.

12. FRANCE

Article L122-4 of Environmental Code states that what should be covered by a SEA are the plans, schemes, programmes and other planning documents adopted by the State, local authorities, etc... related to agriculture, sylviculture, fishing, energy or to industry, transport, waste management, water management, telecommunications, tourism and land management.
There are some exceptions to this, e.g. plans affecting a small surface area.

13. CANADA

The following represents the text of the Cabinet Directive on SEA:

The cabinet directive on the environmental assessment of policy, plan and program proposals. Consistent with the government's strong commitment to sustainable development, ministers expect that policy, plan and program proposals of departments and agencies will consider, when appropriate, potential environmental effects. More specifically, ministers expect a SEA of a policy, plan or program proposal to be conducted when the following two conditions are met:

1. the proposal is submitted to an individual minister or Cabinet for approval; and
2. implementation of the proposal may result in important environmental effects, either positive or negative.

Departments and agencies are also encouraged to conduct SEA for other policy, plan or program proposals when circumstances warrant. An initiative may be selected for assessment to help implement departmental or agency goals in sustainable development, or if there are strong public concerns about possible environmental consequences. Ministers expect the SEA to consider the scope and nature of the likely environmental effects, the need for mitigation to reduce or eliminate adverse effects, and the likely importance of any adverse environmental effects, taking mitigation into account. The SEA should contribute to the development of policies, plans and programs on an equal basis with economic or social analysis; the level of effort in conducting the analysis of potential environmental effects should be commensurate with the level of anticipated environmental effects. The environmental considerations should be fully integrated into the analysis of each of the options developed for consideration, and the decision should incorporate the results of the SEA. Departments and agencies should use, to the fullest extent possible, existing mechanisms to involve the public, as appropriate. Departments and agencies shall prepare a public statement of environmental effects when a detailed assessment of environmental effects has been conducted through a SEA. This will assure stakeholders and the public that environmental factors have been appropriately considered when decisions are made.

No information was found in the Directive or the associated guidelines relating to the activities covered.

APPENDIX D

An example of a possible structure for risk assessment for a CCS project.

Element	Examples of risk & uncertainty sources
Strategic	• Project objectives • Corporate strategy • Country risk • Stakeholders • Alternative project options
CO_2 capture (technical)	• HSE risks (e.g. fire, explosions) • Facility (source of CO_2) closure • Fuel switch (to a less carbon intensive fuel) • Availability • Capacity • Scheduling • Expenditure (CAPEX and OPEX)
CO_2 transport (technical)	• HSE risks (e.g. pipeline laying, pipeline raptor, shipping collisions) • Availability • Capacity • Scheduling • Expenditure
CO_2 injection (technical)	• HSE risks (e.g. compressor failure and operator error during injection) • Availability • Capacity • Scheduling • Expenditure
CO_2 storage and monitoring (technical)	• Storage formation capacity • Well/ drilling CO_2 leakage mechanisms (e.g. leakage through active or abandoned wells, well blow out, future drilling breaks storage formation containment/integrity, water removed from reservoir leading to possible loss of CO_2, Unknown/ old exploration wells) • Storage formation CO_2 leakage mechanisms (existing faults, by seismic activity caused by CO_2 injection, fault caused by natural seismic activity, gaps in cap rock, cap rock damaged by pressure of injection, diffusion of CO_2 through cap rock and other layers, dissolution of cap rock, dissolved CO_2 migrates laterally out of the storage formation,) • Receptors for CO_2 leakage (e.g. atmosphere, agricultural land, highly-populated areas, Vadose zone, lakes in regions that are not strongly seasonal, caves and indoor environments, ground water, seas and oceans, deep sub-surface, Benthic sediments, risk to environmental ecosystems and organisms within etc) • CO_2 leakage detection • Other users of storage formation • Terrorism • Expenditure

Element	Examples of risk & uncertainty sources
Market	• Oil/gas/electricity price • Customers • Physical access to market • Average price of GHG credits • Volatility of GHG credits market • Exchangeability of credits • Long-term market existence and form.
Commercial	• Contract term and liabilities • Bond requirements • Reservoir ownership transfer
Finance	• Financing requirements • Interest rate • Taxes (including environmental taxes) • Government support • Kyoto and other international mechanisms
Project management	• Approvals and licenses • Planning • Communication with stakeholders • Long-term responsibilities • Risk management
Project partners	• Relationship between partners • Compatibility of partners • Level of partner interest • Individual partner exit options • Future collaboration opportunities • Partner bankruptcy

APPENDIX E

1.0 Monitoring of carbon storage projects

Introduction

In small concentrations CO_2 is a relatively benign chemical. However, in large concentrations it poses a risk to humans and the ecosystem. Natural background concentrations of CO_2 range from 300-400 ppm. According to the American Occupational Safety and Health Administration (OSHA), concentrations of CO_2 exceeding 1000 ppm cause noticeable symptoms in humans (Shuler 2002).

Monitoring of stored carbon post-injection is necessary because it is possible that the CO_2 could leak or seep out of its reservoir. The injection process may cause local stress fractures in the reservoir area or shear-type movements between cap rock and reservoir rock. If fractures occur they have the potential to affect the transport and storage properties of the reservoir resulting in escape of CO_2 to the surrounding environment. Therefore it is essential that monitoring is carried out:

- for health, safety and environment (HSE) purposes;
- for verification of quantity of CO_2 stored, for emissions trading and greenhouse gas (GHG) inventory purposes;
- to monitor the integrity of the reservoir.

Benson (2005) states that there are 5 primary types of measurement that should provide the foundation for monitoring and verification programmes for CCS projects:

- measurement of CO_2 concentrations in the workplace to ensure worker and public safety;
- measurement of emissions from the capture system and surface facilities to verify emission reductions;
- measurement of CO_2 injection rates;
- measurement and condition of the well using well-logs and wellhead pressure measurements;
- measurement of the location of the plume of CO_2 as it fills up the storage formation.

According to the Carbon Sequestration Leadership Forum (CSLF, 2005), monitoring should ideally:

- allow for the safe and stable injection of CO_2 into reservoirs;
- allow the integrity of injection and monitoring wells to be assessed and monitored;
- allow the location and fate of the CO_2 plume in subsurface to be monitored;
- allow the project operator or regulator to assess the accuracy of performance predictions of the project;
- verify that the entire mass of CO_2 that is delivered to the injection wells is being stored in the location that was approved for storage;
- provide early warning of migration from the intended storage reservoir or leaks to the ground surface or sea bed;
- detect and measure the flux of leaks of CO_2 to the biosphere.

In considering what a monitoring programme should consist of, the CSFL Task Force responsible for identifying the gaps in CO_2 monitoring suggested that the following should form part of a monitoring programme:

- monitoring of well bore integrity;
- measurements to determine the mass of CO_2 injected, principally derived from the fluid pressure, temperature, flow rate and gas composition at the wellhead;
- monitoring of pressure during the injection process to ensure safe and stable injection;
- monitoring of the migration and distribution of the CO_2 in the deep subsurface, focusing on the intended storage reservoir, but including any unintended migration out of the storage reservoir;
- monitoring of the shallow subsurface offshore to detect and quantify any CO_2 migrating out of the storage reservoir towards the seabed;
- monitoring the vadose zone onshore to detect and quantify any CO_2 migrating out of the storage reservoir towards the ground surface;
- monitoring of the ground surface and atmosphere to detect and quantify CO_2 leaking into the biosphere;
- monitoring of the biosphere to detect any subtle changes that might be related to increased CO_2 concentrations;
- monitoring of the sea bed and water column to detect and quantify CO_2 leaking to the marine environment or atmosphere;
- monitoring at the injection site to detect and quantify any leakage from surface infrastructure (for worker health and safety) and physical changes to the site (particularly heave), which may be indicative of problems below surface;
- monitoring of the wells, deep subsurface, shallow subsurface and ground surface or sea bed should continue for some period after the injection is terminated to confirm predictions of storage behaviour.

CSFL concluded that any monitoring programme should utilize direct and indirect measurements of CO_2 and should probably also include the use of tracers to pinpoint movement ahead of any advancing CO_2 front – e.g. perfluorocarbon or noble gas tracer compounds. These tracers may also help to distinguish naturally occurring CO_2 from CO_2 leaking from the injection site. The tracers are detected by a series of floats or gilders that carry sensors such as pH electrodes that map the CO_2 tracer field (DETL 2001).

Irrespective of the nature of the monitoring programme, the CSFL report and the report by the OSPAR Commission concluded that a pre-requisite for effective monitoring is the undertaking of baseline surveys prior to any injection of CO_2 into the storage formation. However they acknowledged that this may not always be possible, for example when monitoring an existing Enhanced Oil Recovery project. Comprehensive baseline surveys will allow all subsequent monitoring surveys to be compared to the baseline to evaluate changes that may have occurred.

The following table provides an overview of the techniques that could be utilised to monitor reservoirs and detect leaks:

Table 1: Approaches to Monitoring and Detection

Parameter	Monitoring approaches
CO_2 plume location	2D and 3D seismic reflection surveys. Electrical and electromagnetic methods. Land surface deformation (satellite imaging). Gravity. Reservoir pressure monitoring. Wellhead and formation fluid sampling.
Early warning of site failure	2D and 3D seismic reflection surveys. Wellbore-surface and cross wellbore seismic measurements. Land surface deformation (satellite imaging).
CO_2 concentrations and fluxes at the ground surface	Real time IR based detectors for CO_2. Air sampling and analysis using gas chromatography. Eddy flux towers.
Injection well condition, flow rates and pressure	Borehole logs. Wellhead and formation pressure gauges. Wellbore annulus pressure measurements. Surface CO_2 concentrations near injection wells.
Solubility and mineral trapping	Formation fluid sampling using wellhead or downhole samples-analysis of CO_2, major ion chemistry and isotopes. Monitoring of tracers.
Leakage via faults and fractures	2D and 3D seismic reflection surveys. Electrical and electromagnetic methods. Land surface deformation (satellite imaging). Reservoir and aquifer pressure monitoring. Groundwater and vadose zone sampling.
Groundwater quality	Groundwater sampling and geochemical analysis. Monitoring of tracers.
Ecosystem impacts	Hyper-spectral geo-botanical monitoring. Soil gas surveys. Direct observation of biota.
CO_2 concentrations in vadose zone and soil	Soil gas surveys and gas composition analysis. Vadose zone sampling wells.
Micro-seismicity	Passive seismic monitoring.

Source: adapted from Benson et al 2003.
[Note: the 'vadose zone' is the zone between land surface and the water table within which the moisture content is less than saturation (except in the capillary fringe) and pressure is less than atmospheric

As is evident from column 2 of Table 1 (above), a wide variety of potential monitoring techniques exist. However not all are well known or fully developed. Table 2 (below) provides an overview of the monitoring techniques including an indication as to how well developed they are:

Table 2: Measurement, Monitoring and Verification Technology

Technique	Detection method	State of technological readiness
Time lapse 4D multi- component seismic	Acoustic.	Well known.
Vertical seismic profiling.	Acoustic.	Well known.
Cross well seismic tomography.	Acoustic.	Well known.
Down hole micro-seismic.	Acoustic.	Developmental.
Electrical resistance tomography.	Electrical.	Developmental.
Electromagnetic induction tomography.	Electrical.	Prototype.
Soil gas sampling.	Chemical.	Well known.
Noble gas tracing.	Chemical.	Early testing.
Other gas tracing.	Chemical.	Early testing.
Well head detectors.	Chemical.	Prototype.
Brine sampling.	Chemical.	Well known.
Sub-surface and surface tilt meters.	Physical.	Developmental.
Airborne hyper-spectral imaging.	Optical.	Developmental.
Space based monitoring.	Microwave?	Proposed.

Source: table adapted from a monitoring technology report by the US Lawrence Livermore National Laboratory.

The timescale over which monitoring is likely to be needed raises an issue in itself because it requires some consideration of the objectives of monitoring in the long term. The UK Department of Trade & Industry (DTI) commissioned a report into clean-coal technology, and part of the report focused on the evolution of CCS projects and the changing nature of monitoring. Table 3 (below) is adapted from this report and presents an overview of the possible monitoring objectives for storage projects:

Table 3: Project Evolution and Monitoring Objectives

Project stage	Potential duration	Possible monitoring objectives
Pre- injection.	3-5 years	To develop a geological model. To perform an EIA. To develop predictive models of system behaviour. To develop effective remediation strategies. To establish baseline data against which future site performance can be compared.
Injection.	5-50 years.	To verify the mass stored. To determine the mass if any, that is seeping back to the ocean or atmosphere. To meet local HSE performance criteria. To provide stakeholder confidence, especially during early projects. To confirm, or otherwise, the accuracy of predictive models.
Post-injection.	50-100 years.	For the same reasons as during the injection stage plus: To provide evidence that the system will behave as predicted so that the site may be abandoned.
Post-closure.	-	Not needed.

One of the main challenges associated with detection of leaks from storage reservoirs is how to distinguish background CO_2 from CO_2 derived from leakage/ seepage from reservoirs. Research by Lewicki et al 2005 into the development of an improved strategy for the detection of CO_2 leakage highlights a number of factors that will assist scientists to make the distinction:

- Leaked CO_2 should be relatively coherent in space (i.e. occupies an identifiable space).
- The production of background CO_2 is controlled by a variety of meteorological and biological processes operating on diurnal and seasonal time scales and can be correlated as such. By contrast, CO_2 derived from leaks/seepage is predicted to be relatively constant.
- Data relating to CO_2 fluxes in a particular area where there may be a small CO_2 leak can be adjusted to eliminate temporal variability associated with background processes (meteorological and biological).

2.0 Well Monitoring Techniques

2.1 Fibre Optics

Fibre optic monitoring techniques have been deployed on the Ketsin CO_2 Sink project (a project supported by the EU Commission which involves injecting CO_2 into a saline aquifer near the town of Ketsin, west of Berlin). Monitoring involves a fibre optic sensor (consisting of a light source, a sensing area and a detector unit) being permanently placed into the reservoir. Research indicates that fibre optic sensors can provide reliable and precise information on quantities such as strain, stress, pressure, temperature and pH. Down-hole monitoring is believed to have a number of advantages compared to conventional sensors – e.g.: remote operation at distances of more than 10km; no down-hole electronics are required; reliability in hostile environments; and point or distributed monitoring.

The monitoring concept relies on ‘smart casing’ whereby the sensors are placed behind the well casing or are designed as an ‘in-casing solution’. The Ketsin project team intends to cement the sensors in the annular space between the casing and rock formation with a special protection system in place to minimise the possibility of damage to the fibre optic cables and sensors during and after installation.

The discussion paper produced by the CSLF concludes that fibre optic systems are useful for measuring pressure fluctuations in storage reservoirs and at the surface level enabling better control of pressure in the injection well system. It is possible to tie-in an emergency shutdown system so that if the pressure exceeds pre-set thresholds the shutdown system is triggered. Fibre optic systems exist that can be used to identify fluid exchange zones between a borehole and surrounding formations via a series if fibre optic temperature sensors. The CSLF experts conclude that the pressure and gas composition in the annulus can be continuously monitored to verify the integrity of the injection string and the packer inside the well casing that is used to isolate the injection zone from the well.

2.2 Electrical Techniques including Self Potential

Electrical monitoring techniques are designed to measure the natural or induced electrical or magnetic fields in the earth. Induced electricity currents can be used to measure the resistance of a formation. Changes in the resistance will occur as a consequence of, for example, dissolution of minerals in the rock formation (cause a decrease in resistance) or displacement of saline by CO_2 (causes an increase in resistance). Analysis involves comparison of electrical or magnetic fields pre-injection to post-injection measurements to determine the presence of CO_2 which changes the characteristics of these fields (CSLF 2005).

Self potential is the ability of the earth to generate its own electrical fields which can be measured. Migration of CO_2 from an injection well can produce an electrical potential that can be measured. CSLF believes that this technique could prove useful in the monitoring of plume migration.

2.3 Seismic Imaging

A report conducted for the DTI in 2003 concluded that 4D surface seismic monitoring as employed on the Sleipner sequestration project will probably lead the way for offshore monitoring of CO_2 stored in brine aquifers but only in situations where there are only a limited number of wells in the reservoir and where other sources of data are not readily available because the costs involved do not make it a cost-effective monitoring technique.

Field studies conducted by Al Saleh (research published 2005) seem to support the conclusions of the DTI report to some extent. Saleh argues that if seismic technology is going to be deployed to monitor the CO_2, it should be able to monitor the gas in real-time. He concludes that time-lapse seismic 4D imagery appears to be the most promising technique. The technique has been used successfully for over 10 years to monitor the movements of gas injected into conventional oil and gas reservoirs under the guise of enhanced recovery programmes.

The principle behind the technique is detection in reduction in seismic velocity and bulk of the gas resulting from the advance of a gas phase into a liquid saturated body of porous rock (Saleh 2005). Accelerometers, geophones or a combination of both are used to monitor seismic activity. They are usually based on a mass-loaded spring concept whereby the relative movement between the mass and the case of the accelerometer is measured.

While CSLF acknowledges that seismic imaging currently provides the most accurate method of detecting CO_2 in sub-surface areas around wells, it has its limitations. In particular, there are problems associated with resolving impedance contrast between reservoir rock with pores filled with water containing dissolved CO_2 and rock in which pores contain water without dissolved CO_2. Another limitation associated with the technique is that the resolution of images deteriorates with depth as a result of weakening of signal.

The most important factor in seismic monitoring is resolution - the size of a feature that can be detected. Cross-well seismic monitoring will yield more information than monitoring from a single well. Seismic imaging can be used to detect changes in velocity, reflectivity and potentially attenuation (Harris 2004). The majority of changes in velocity resulting from saturation of rock occur with only a small amount of CO_2 leakage into pore space. This means that seismic monitoring should be able to detect thin layers of CO_2 - highlighting possible migration paths (Harris 2004).

2.4 Geochemistry / Fluid Sampling

According to the OSPAR Commission, geochemical techniques could be utilised to monitor stored CO_2. The techniques involve analysing the chemistry of fluids and gases in and around the storage site, the results of which can then be compared to background levels in the area.

The Ketsin project team intends to deploy a programme for permanent and direct monitoring of gases and brine. A number of analysis techniques are available, for example:
Electro-chemical multi-sensor modules: the Ketsin project team concluded that this technique was most suitable for monitoring CO_2 dissolved in groundwater wells. The system enables long-term unmanned monitoring of pH, dissolved CO_2, temperature, electrical conductivity and water level.

It should be noted that in addition to collecting data from wells, adequate data should be collected relating to natural, local and seasonal background CO_2 fluctuations. In addition to collecting well data, the Ketsin team set up a meteorological station to collect information relating to local weather conditions (ambient temperature, pressure, rainfall, wind and moisture). The data is necessary to correlate and correct the geochemical data.

Another monitoring technique involves the collection of fluid samples from the injection zone via monitoring wells. Changes in the chemistry of the fluid – e.g. alkalinity, HCO_3^-, or resistance levels can be evaluated to determine whether CO_2 has leaked into the monitoring well. Analysis of the CO_2 itself can be used to determine whether it is naturally occurring CO_2 or injected (the isotopic composition of carbon in injected carbon can be different from that of naturally occurring carbon) (CSLF2005).

Tracers can be injected into the injection well to assist with detection of route and transport rate of CO_2 outside the injection well. As indicated in the introduction, tracer compounds can be gases such as perflourocarbons, noble gases, Isotopes or SF6 (Benson 2002); all can be detected at low concentrations (CSLF 2005).

Techniques exist that enable monitoring holes to be drilled through the casing and cement into the reservoir well to enable samples to be collected directly from the storage reservoir. The holes can be plugged at the same time to prevent leakage, however the CSLF concludes that the technique is expensive but could be used for periodic testing above the injection zone without the drilling of specific monitoring wells.

In relation to detection of anomalous CO_2 leakage into ground and surface waters, detection could be accomplished by sampling of the water and analytical analysis to determine if CO_2 is present. Dissolution of CO_2 into ground and surface waters will tend to increase acidity (decrease the pH) of the waters. A relatively large magnitude CO_2 leakage flux into ground or surface water could produce CO_2 gas bubbles. In this case, gases associated with waters could be sampled and the isotopic compositions of CO_2 could be identified to determine if the source is stored carbon dioxide or naturally occurring CO_2 (Oldenburg et al 2003).

Geochemical techniques proved useful for documenting the evolution of CO_2 plume in the Frio brine formation sequestration project. Gas analysis detected leakage of CO_2 into an observation well and aqueous geochemistry documented the evolution of formation waters as CO_2 interacted with rock and brine (Hovorka et al 2005).

2.5 Gravimetric Techniques

Gravimetry is the measurement of gravitational force, weight, or density. It can be used when either the magnitude of gravitational force or the properties of matter are of interest. Gravity techniques - be they marine, ground or aerially based - can be used to detect variations in the density of rock or fluid in the sub-surface region (variations caused by, for example, injection of a lighter fluid into the pore spaces of a reservoir rock) (CSLF 2005). A report by the OSPAR Commission concluded that such techniques should only be deployed in a site-specific manner to detect leaks and, according to Harris (2004), it is only suitable for making low resolution mass balance measurement.

2.6 Satellite Imaging

It is argued that satellite imaging could be deployed for gas tracking and for tracking algal blooms associated with leaks of CO_2 (DTI 2003): however, it would only be an indirect indication of the presence of a leak.

NASA is currently undertaking research into the use of satellites to determine changes in biomass – e.g. forests over large areas which could indicate changes in chemical composition of the ecosystem (Goddard Space Flight Centre / Langley Research Centre). Observations made by the satellites could theoretically be used to monitor carbon sinks over a large area.

2.7 Bio-indicators / Soil Monitoring / Marine Biota

The report for the DTI in 2003 concluded that these techniques are only likely to work in situations where CO_2 has been stored in shallow reservoirs on land or in the sea bed because it could prove too difficult to differentiate sources of growth for the various bio-indicators. The authors of the report concluded that such monitoring is believed to be too indirect and low resolution for the detection of leaks.

According to the CSLF, it is unclear to what extent CO_2 measuring devices currently used by marine biologists can be adapted for benthonic settings. Very little is known about the use of changes in ecosystems or presence of indicator species to detect leakage of CO_2.

Soil gas CO_2 concentrations can be rapidly measured at many locations over large areas using a soil probe and a portable infrared gas analyser (IRGA). This method requires inserting a soil probe to the depth of interest - usually less than 1m - and measuring CO_2 concentrations (typically to ± 100 ppmv or 0.01%) as the gas is pumped from the soil to the IRGA by an internal pump. Alternatively, a gas sample can be collected from the probe using a syringe and vial. The chemistry of gas samples can then be analyzed in the laboratory using standard gas chromatographic techniques (Oldenberg et al 2003).

3.0 Atmospheric Monitoring

The main challenges associated with atmospheric modelling are how to distinguish between leaks from geo-stored CO_2 and variable natural atmospheric CO_2 and how to quantify the flux, especially in relation to slow and diffuse leakage (Etheridge et al 2006). Research by Etheridge et al concluded that a number of techniques may be suitable, for example micro-meteorological methods or continuous atmospheric CO_2 measurements combined with transport modelling. Tracers added to the stored CO_2 will assist with atmospheric detection. The authors believe that the advantages of atmospheric modelling will be most useful when used in conjunction with some form of sub-surface monitoring.

Two types of hand-held chemical sensors are already in existence, one utilising gas chromatography, the other utilising Draeger tubes. Draeger tubes are used to identify the amount and type of a particular chemical constituent in the atmosphere, and rely on a chemical reaction to identify the nature and type of a particular chemical constituent in the atmosphere. They are adequate to check for dangerously high levels, but not for subtle changes (Shuler et al 2002).

Direct measurement of CO_2 in air is most commonly done through infrared gas sensors (IRGAs): CO_2 has unique absorption bands in the infrared range. An infrared sensor typically consists of a chamber which the sample gas is passed through. If gas which absorbs a particular wavelength or IR energy is present in the sample flowing through the detection chamber, it will reduce the amount of IR energy that reaches the detector. The measuring circuit compares this IR energy to the energy that is present when fresh air is in the chamber and interprets the signal and processes it as a measured reading of the detected gas.

IRGAs are proven and reliable devices, reasonably priced, and readily transportable. Consequently, they have been used in a broad range of studies including monitoring atmospheric CO_2 concentration, occupational health and safety monitoring, pipeline leak detection, ecosystem measurements, volcanic efflux research, micrometeorological research, crop respiration measurements, and human physiology studies (Oldenburg et al 2003).

4.0 Pipeline Monitoring Techniques

A report completed by DNV for the DTI in 2003 concluded that there were a number of options available to organisations to assist with monitoring the integrity of pipelines, as set out below.

4.1 Visual Inspection

The Pipelines Industries Guild recommends that an onshore oil or gas pipeline operator undertakes an aerial survey of the pipelines every 2-4 weeks and completes a line-walking inspection exercise once every 6-12 months. In relation to offshore pipelines, a different approach is necessary, utilising divers and remotely operated vehicles (ROVs) to conduct the inspections.

4.2 On-line Flow Monitoring

The report concluded that operators of hydrocarbon pipelines should undertake some sort of pipeline mass-balance, by comparing inlet and outlet pipeline flow rates. Pressure drop monitoring can also be utilised to detect unexpected variations. Operators could deploy a technique known as Real Time Transient Modelling (RTTM) which involves computer simulation of pipeline conditions using fluid mechanics and hydraulic modelling. RTTM software can predict the size and location of leaks by comparing measured data for a segment of pipe with the predicted modelling conditions.

4.3 Pressure Monitoring

Pressure testing can be useful for checking large sections of pipeline. It can be undertaken with fluid in the pipeline: however, this can be potentially dangerous if the pipe fails. Out-of-service testing using water is a preferred option because it can be performed at higher pressures and provide greater confidence in the pipe. The main disadvantage of such a test is that it does not indicate how close to failure a pipeline might be.

4.4 Corrosion Monitoring

The monitoring of corrosion using metal probes inserted directly into the pipeline flow is an established technique for monitoring corrosion. The probes are weighed prior to insertion into the flow and again after a specified time period in the flow in order to estimate the extent of corrosion (e.g. electrical resistance probes). When exposed to a corrosive environment, the cross-section of the wire loop is reduced which increases the resistance of the sensing element resulting in a change in the output of the electrical resistance meter (DTI 2003).

4.5 Wall Analysis

Methods for monitoring corrosion inside pipelines include 'intelligent pigging'. A 'pig' is analogous to a bullet, and can be fired down a pipeline for numerous reasons, conventionally to clean the pipeline. More recently, pigs have been developed to undertake monitoring. A 'calliper pig' will continuously measure the internal diameter of the pipeline, identifying areas of corrosion (destruction by chemical action) and erosion (wearing away of material). An example of intelligent pigging in application is that of ‘pulse eddy currents’ (PEC), a non-destructive technique used to identify surface and near-surface defects in small regions of pipe. X-ray radiographic analysis can also be used to inspect pipelines, and is currently most often used to inspect pipeline welds.

4.6 Breach Detection Techniques (based on experience from existing hydrocarbon pipelines)

Vapour Sensing

Hydrocarbon gas-sensing is most often deployed in relation to detection near storage tanks. However, the DTI report identified that it can also be applied to pipeline systems. It works on the principle of detecting build-up of gas in the pore space in the soil surrounding the pipeline. Samples can be collected from the pore space for spectroscopic analysis. The analysis is designed to identify the molecular structure of the gas sample and to determine whether hydrocarbon vapours are present. To assist in detection, a chemical tracer can be injected into the pipeline flow which, if found in the soil sample, will indicate the presence of a leak.

Acoustic Emissions

Acoustic emissions monitoring works by utilising acoustic sensors fixed to the outside of the pipe to build up an ‘acoustic map’ based on the internal pipeline noise. If fluid or gas escapes from the pipeline it will register as a noise that is different to the background flow, thereby detecting a leak in the pipeline.

Fibre Optics

Hydrocarbon leaks can be detected by locating fibre optic probes near to the pipeline. The fibre optic cable is covered in a special coating that changes the refractive index in the presence of hydrocarbons.

5.0 Subsea Monitoring Techniques

5.1 Echo Sounding / Swath Bathymetry

According to a report by the CSLF, CO_2 rising to the sea-bed level could be detected via the use of echo-sounding or swath bathymetry (sea-floor mapping) to detect changes in the morphology of the sea-bed. Both techniques are routinely deployed in the oil, gas and marine surveying industries. The presence of CO_2 bubble trains in seawater could also be detected by echo-sounding. Echo-sounding involves the use of deep-towed boomer surveys to detect the presence of CO_2 in the shallow zone beneath the seabed.

6.0 Near Surface Monitoring

6.1 Accumulation Chamber and Eddy Correlation

Two basic approaches exist for measuring CO_2 fluxes: the accumulation chamber (AC); and the eddy correlation (EC) approach. In the AC method, an open-bottomed chamber is placed directly on the soil surface or on a collar installed on the ground surface and the rate of soil-

CO_2 accumulation is measured using an IRGA. This approach provides a small-scale measurement of soil- CO_2 flux. The measurement is relatively quick and many such measurements can be made over a large area. The EC method provides a spatially-averaged flux by correlating CO_2 concentration measured at a fixed height above the ground using an IRGA with local meteorological variations at the same elevation. After averaging (based on time) of the local variations of concentration and vertical wind speed, an average flux over a given footprint is derived. The footprint area is a function of the instrument height above the ground surface and local wind velocity, and is of the order of 10–100 times the instrument height (Oldenburg et al 2003).

6.2 Light Detection and Ranging

Light detection and ranging (LIDAR) is the optical analogue of radar, using laser radiation to probe the atmosphere, and can be used to measure trace atmospheric gases (e.g., NO_2, SO_2, O_3, H_2O, CH_4, CO_2). While there are a range of LIDAR techniques in use, atmospheric CO_2 can be measured (Oldenburg et al 2003) by two LIDAR methods: (1) Raman LIDAR, and (2) differential absorption LIDAR (DIAL).

The Raman LIDAR method involves transmitting laser light into the atmosphere and then detecting the laser radiation that has been shifted in wavelength due to interaction with the target scattering molecules along the resolved path length. Raman scattering provides wavelength shifts that are distinct for the target molecules (e.g. CO_2), according to the vibrational energy states of the molecules. In the case of CO_2, the backscattered power of the wavelength-shifted signal is proportional to the CO_2 concentration. By comparing the Raman signal of the CO_2 to the Raman signal of N_2 or O_2, a direct measurement of CO_2 concentration can be obtained.

The DIAL technique involves using a tunable laser at two wavelengths to estimate the concentration of a target-absorbing species (e.g. CO_2). In the case of CO_2, one wavelength is selected to coincide with the centre of a CO_2 absorption line and the second wavelength is selected to fall in a nearby non-absorbing region. Laser power at both wavelengths is transmitted either sequentially or simultaneously over the same path in the atmosphere and is elastically scattered into the field of view of the LIDAR receiver. The average CO_2 concentration over the path length can be determined from the ratio of the backscatter signals for the two laser wavelengths.

6.3 Hyper-spectral Imaging of Vegetative Stress (Oldenberg et al 2003)

Hyper-spectral imaging measures the absorption of specific wavelengths of light from visible through infrared by material exposed on the surface of the earth. It is based on principles similar to infrared absorption by CO_2; however, in the case of hyper-spectral imaging, images covering many narrow, contiguous wavelength bands are simultaneously collected. A spectral response indicative of the exposed material on the earth's surface is then extracted from each pixel in the image. Because the absorption features in the spectra are determined by the chemical composition and physical structure of surface materials, they can be used to identify these materials.

7.0 Monitoring of Existing CCS Projects

The following provides an overview of the key monitoring techniques employed on existing storage projects:

- Sleipner, SACS (brine formation storage): 3-D seismic, (gravity)

- Weyburn, Canada (EOR storage): 3-D seismic, cross-well; geochemical monitoring, reservoir and soil-gas; performance assessment and optimization; risk assessment
- Frio Formation, Texas (Brine formation storage): pressure, geochemistry, groundwater
- West Pearl, New Mexico (EOR): 3-D seismic, cross-well; geochemical monitoring
- Lost Hills, California (EOR): cross-well seismic, EM, tracers
- Vacuum, New Mexico (EOR): electrical resistance tomography.

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