INTERNATIONAL MARITIME ORGANIZATION

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MEETING OF THE SG INTERSESSIONAL
TECHNICAL WORKING GROUP ON CO2
SEQUESTRATION
3 – 7 April 2006
Agenda item 7

LC/SG-CO2 1/7
3 May 2006
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REPORT OF THE MEETING OF THE SG INTERSESSIONAL TECHNICAL WORKING GROUP ON CO_2 SEQUESTRATION

1 INTRODUCTION

1.1 The Meeting of the SG Intersessional Technical Working Group on CO_2 Sequestration was convened at IMO Headquarters, London, from 3 to 7 April 2006 under the Chairmanship of Mr. Todd Bridges (United States).

1.2 Delegations from the following 13 Contracting Parties to the London Convention 1972 attended the Meeting:

AUSTRALIA
CANADA
CHINA
FRANCE
GERMANY
JAPAN
NETHERLANDS
NIGERIA
NORWAY
REPUBLIC OF KOREA
SPAIN
UNITED KINGDOM
UNITED STATES

1.3 Delegations from the following eight Contracting Parties to the 1996 Protocol to the London Convention 1972 also attended the Meeting:

AUSTRALIA
CANADA
FRANCE
GERMANY
NORWAY
SAUDI ARABIA
SPAIN
UNITED KINGDOM

1.4 An observer from the following State that is neither a Contracting Party to the London Convention 1972, nor to the 1996 Protocol also attended:

TURKEY

1.5 An observer from the following intergovernmental organization attended the Meeting:

ORGANIZATION FOR ECONOMIC CO-OPERATION AND DEVELOPMENT/
INTERNATIONAL ENERGY AGENCY (OECD/IEA)

1.6 Observers from the following international non-governmental organization also attended the Meeting:

GREENPEACE INTERNATIONAL

Opening of the Meeting

1.7 In opening the proceedings, the Chairman welcomed all participants to the Meeting of the SG Intersessional Technical Working Group on CO_2 Sequestration.

Terms of Reference

1.8 The 27th Consultative Meeting had instructed the Working Group to:

.1 make an assessment of the potential risks and a general assessment of the benefits to the marine environment of CO_2 sequestration in sub-seabed geological structures, henceforth to be called "CS-SSGS", within the scope of the London Convention and the Protocol;

.2 develop an assessment framework ensuring compatibility with Annex 2 to the London Protocol;

.3 identify relevant gaps in knowledge;

.4 reach a view on the implications of CS-SSGS for the marine environment; and

.5 report its findings to the 29th session of the Scientific Group.

Address of welcome

1.9 The Secretary of the Meeting, Mr. René Coenen, recalled that, when the Scientific Group in May 2005 discussed for the first time in detail the scientific and technical aspects of sequestration of CS-SSGS, it laid the groundwork for this intersessional meeting in concluding that such sequestration was technically feasible, but also that there were gaps in knowledge related to possible impacts on the marine environment and in technology, such as monitoring techniques, which needed to be addressed. He also recalled that the Working Group in carrying out its tasks was expected to make use of relevant information from other fora, in particular the IPCC Special Report on Carbon Dioxide Capture and Storage, published in September 2005.

1.10 The Secretary informed the Meeting that, on 24 March 2006, the 1996 Protocol to the London Convention 1972 (London Protocol) had entered into force following the accession of Mexico to it as its 26th Contracting Party and, consequently, the 1st Meeting of Contracting Parties to the London Protocol would be convened in conjunction with the 28th Consultative Meeting (30 October to 3 November 2006). This major development enabled the Contracting Parties to both agreements to consider what action to take with regard to facilitation and/or regulation of CO_2 sequestration in sub-seabed geological structures.

1.11 He also informed the Meeting that, in 2003, the IMO Assembly, by its resolution A.963(23), adopted "IMO Policies and Practices related to the Reduction of Greenhouse Gas Emissions from Ships". In this resolution, the Assembly urged the Marine Environment Protection Committee (MEPC) to undertake further work to identify and develop the necessary mechanisms needed to achieve limitation or reduction of greenhouse gas emissions from international shipping. As a follow-up, the MEPC agreed to approach this policy directive from a technical and methodological perspective and to concentrate the work on CO_2 emissions from shipping rather than the six greenhouse gases identified by the UN Framework Convention on Climate Change. Work on this issue would continue in the Committee. To put this activity in context, an IMO study carried out in 2003 estimated that ships contributed 1.8 percent to the world's total CO_2 emissions. However, in view of an expected reduction of CO_2 emissions from land-based sources and of a continuing increase in international trade most of which is carried by ships, the contribution from the shipping sector was likely to rise. These trends would, therefore, warrant further action from the maritime sector on CO_2 emissions.

1.12 In responding, the Chairman thanked the Secretary for his remarks and advice and also the members of the intersessional Correspondence Group on CO_2 Sequestration and several presenters in attendance for their contributions to the preparation of the programme for this Meeting.

Adoption of the agenda and organization of the work

1.13 The Working Group adopted the agenda for this Meeting, as shown at annex 1 to this report. This annex includes a list of documents submitted to the Meeting.

1.14 The Working Group agreed that the aim was to address all items of the terms of reference, and, in particular, to inform the development of generic guidance for CS-SSGS, in order to:

.1 characterize the risks to the marine environment from CO_2 sequestration on a site-specific basis; and

.2 collect the necessary information to develop a management strategy to address uncertainties and any residual risks.

1.15 Presentations were given on the various elements to be included in the risk assessment and management framework, which were followed by detailed discussions. For this task, the Working Group drew also on several sources of information, and especially the following documents:

.1 the IPPC Special Report on Carbon Dioxide Capture and Storage (LC/SG-CO2 1/INF.4); and

.2 "Placement of CO_2 in Sub-seabed Geological Structures" (LC/SG-CO2 1/INF.2) and "Effects on the Marine Environment of Ocean Acidification Resulting from Elevated Levels of CO_2 in the Atmosphere" (LC/SG-CO2 1/INF.3). Both documents had been prepared in the framework of the OSPAR Convention.

2 CONCLUSIONS AND RECOMMENDATIONS

2.1 As instructed under item 1 of its terms of reference, the Working Group prepared the "Evaluation of the Benefits and Risks of CO_2 Sequestration in Sub-Seabed Geological Structures (CS-SSGS)", which is shown in annex 2 to this report.

2.2 As instructed under item 2 of its terms of reference, the Working Group developed the "Risk Assessment and Management Framework for CO_2 Sequestration in Sub-Seabed Geological Structures (CS-SSGS)", which is shown in annex 3 to this report.

2.3 The Working Group considered that CS-SSGS was a waste management option that should be considered in the context of Contracting Parties' approaches to mitigating greenhouse gas emissions. The "Risk Assessment and Management Framework for CS-SSGS", as developed, had not addressed, in detail, the waste prevention audit and the waste management options, which are requirements of Annex 2 to the London Protocol. As Contracting Parties were required to address these matters in the assessment of CS-SSGS, further consideration may therefore be necessary.

2.4 As instructed under item 3 of its terms of reference, the Working Group identified several areas of uncertainties and data gaps[1] in the Risk Assessment and Management Framework, which need to be taken into account when using the Framework.

2.5 The Working Group arrived at the following overall conclusions and implications, some of which addressed item 4 of the terms of reference:

.1 Ocean acidification and other global effects on the marine environment caused by elevated emissions of CO_2 are a cause of serious concern. Mitigation of these impacts necessitates a portfolio of options to reduce levels of atmospheric CO_2. As one such option, CS-SSGS is considered to be technically feasible, using established technologies;

.2 The benefits of CS-SSGS have the potential to make a substantial contribution to reducing CO_2 emissions to the atmosphere, thus preventing these emissions from being absorbed into the oceans and providing mitigation of ocean CO_2, carbonate and pH change, effects on sensitive biological systems and nutrient availability and cycles. The potential risks posed by CS-SSGS are focused primarily at the local scale and include the potential for impacts on the marine environment in proximity to the receiving reservoir;

.3 CS-SSGS is a waste management option to be considered within the context of Contracting Parties' approaches to mitigating greenhouse gas emissions[2];

.4 CO_2 injection streams may contain other substances derived from the source material. The actual composition of the injection streams intended for sequestration in the sub-seabed will therefore vary in their content of CO_2 and other substances depending on the nature of the source material and the methods used for CO_2 capture and liquefaction to super-critical temperatures and pressures.

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[1] See annex 3 to this report in paragraphs 3.17, 4.12, 5.8, 5.9 and 6.24.

[2] This option includes CO_2 sequestration in depleted oil and gas fields, but excludes normal oil and gas exploitation operations, such as enhanced oil recovery (EOR).

However, it must be stressed that none of these other substances will have been deliberately added to the CO_2 stream for the purposes of waste disposal;

.5 Long-term monitoring and mitigation of any leakage of CO_2 will be important activities in the context of the London Convention and Protocol, due to the long time-scales of CS-SSGS, the potential for much larger sites than those used for conventional dumping operations and the nature of CO_2;

.6 There is significant potential for geological storage in structures beneath the oceans. Oil and gas reservoirs and saline formations are expected to have the largest potential to accommodate safe, long-term storage. The aim is to retain CO_2 permanently. Because of the various trapping mechanisms, storage may, in some cases, become more secure over time;

.7 Because every site is expected to differ in regard to the properties affecting its suitability as a storage site, several important issues should be considered during the site screening and selection process for CS-SSGS, including: the storage capacity and injectivity of the geological formation; the storage integrity; the suitability of the surrounding geological formations; potential migration and leakage pathways over time; and the potential effects on marine life and human health of leakage of CO_2;

.8 Monitoring techniques for the detection of migration and potential leakage of CO_2 from the intended storage formations are available. The relevant time frames pose challenges with respect to management of the response capacity;

.9 Although the intention of the process of CS-SSGS is ‘no leakage’, the need for implementing mitigation measures in response to potential leakages should be based on the likelihood that CO_2 will reach the marine environment and the types and magnitudes of consequent effects; and

.10 The ‘Risk Assessment and Management Framework for CS-SSGS’ can provide useful and important information regarding site-specific risks to the marine environment posed by CS-SSGS, for developing management strategies to address uncertainties and to reduce residual risks to acceptable levels.

2.6 The Working Group noted that the Risk Assessment and Management Framework for CS-SSGS, as developed, would be useful for further work by the Scientific Group, in particular, the development of more specific guidelines for assessment of CS-SSGS, using the “Generic Guidelines”[3] as a basis.

2.7 The Working Group agreed that the conclusions it had reached at this session should be distributed to the CM Intersessional Legal and Related Issues Working Group on CO_2 Sequestration (10 to 12 April 2006) for its information.

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[3] The “Guidelines for the Assessment of Wastes or Other Matter that May be Considered for Dumping” were adopted in 1997 under the London Convention and Protocol and are based on Annex 2 to the Protocol.

3 CONSIDERATION AND ADOPTION OF THE REPORT

The Meeting of the SG Intersessional Technical Working Group on CO_2 Sequestration adopted its report on Friday, 7 April 2006.

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ANNEX 1

AGENDA FOR THE SG INTERSESSIONAL TECHNICAL WORKING GROUP ON CO_2 SEQUESTRATION

1 Adoption of the agenda

LC/SG-CO2 1/1	Secretariat:	Provisional Agenda
LC/SG-CO2 1/INF.5	Secretariat:	Programme for the Meeting

2 Continuation of a review of the benefits of CO_2 sequestration in sub-seabed geological structures and of new information relevant to the protection of the marine environment

LC/SG-CO2 1/INF.2	Secretariat:	Placement of CO_2 in Sub-seabed Geological Structures (OSPAR)
LC/SG-CO2 1/INF.3	Secretariat:	Effects on the Marine Environment of Ocean Acidification Resulting from Elevated Levels of CO_2 in the Atmosphere (OSPAR)

3 Consideration of the IPCC Special Report and other relevant information

LC/SG-CO2 1/INF.4	Secretariat:	IPCC Special Report on Carbon Dioxide Capture and Storage

4 Development of a 'risk assessment framework'

No documents submitted under this item

5 Conclusions and recommendations

No documents submitted under this item

6 Any other business

No documents submitted under this item

7 Consideration and adoption of the report

LC/SG-CO2 1/WP.1	Draft report	
LC/SG-CO2 1/INF.1	Secretariat:	List of Participants

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ANNEX 2

EVALUATION OF THE BENEFITS AND RISKS OF CO_2 SEQUESTRATION IN SUB-SEABED GEOLOGICAL STRUCTURES (CS-SSGS)

Background

1 The 26th Consultative Meeting had considered the challenges of stabilizing greenhouse gas concentrations in the atmosphere and recognized that CO_2 capture and storage in geological structures might offer important possibilities for climate change mitigation policies. In this context and in accordance with Article 2 of the 1996 Protocol, the Meeting had agreed that the issue of long-term CO_2 sequestration should be included in its work programme and to initially focus on CO_2 sequestration in sub-seabed geological structures (CS-SSGS). This approach includes CO_2 sequestration in depleted oil and gas fields, but excludes normal oil and gas exploitation operations, such as enhanced oil recovery (EOR).

2 The 28th session of the Scientific Group carried out an initial assessment of the potential environmental risks and benefits for the marine environment of CS-SSGS within the scope of the London Convention and Protocol, including the identification of gaps in knowledge.

3 The report of the SG Technical Working Group on CO_2 Sequestration (LC/SG 28/14, annex 5) mentioned that impacts on the marine environment of acidification caused by high levels of anthropogenic CO_2 are a cause of serious concern and that mitigation of these impacts requires a portfolio of measures to reduce levels of atmospheric CO_2. The magnitude of ocean acidification can be predicted with a high level of confidence. The impacts of ocean acidification on marine organisms and their ecosystems are much less certain but it is likely that, because of their particular physiological attributes, some organisms will be more affected than others. There is convincing evidence to suggest that acidification will affect the process of calcification in animals such as corals and molluscs that use calcium carbonate for structural purpose. Other organisms that may be affected are components of the phytoplankton and the zooplankton which are a major food source for fish and other organisms[4].

4 Potential risks to the marine environment of CS-SSGS are of the same general nature as those discussed above, though at a local scale. Potential risks include those associated with the other substances in the CO_2 injected stream.

5 In general, there are four different levels of concern for leakage:

.1 the global dimension concerns the impacts on climate and the oceans;

.2 the local dimension is site-specific and includes the effects on the marine environment which are a principal focus of the London Convention;

.3 the short-term consequence of leakage might be an acute danger to human health and living marine resources; and

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[4] OSPAR 2006. Effects on the Marine Environment of Ocean Acidification Resulting from Elevated Levels of CO_2 in the Atmosphere (LC/SG-CO2 1/INF.3).

.4 the <u>long-term</u> consequences of CO_2 leakage might be acidification and negative impacts on marine ecosystems.

6 CO_2 sequestration technologies have the potential to make a substantial contribution to reducing CO_2 emissions to the atmosphere, thus preventing those emissions from being absorbed into the oceans. As such, it would (in combination with other measures) have direct benefits for the marine environment in mitigating:

.1 changes in ocean CO_2, carbonate and pH levels;

.2 the effects of increased anthropogenic CO_2 levels on sensitive biological systems such as coral reefs; and

.3 the risk that lower pH may change the availability of key nutrients (e.g. nitrogen and phosphorus) required for phytoplankton growth and ocean productivity.

7 In addition to those direct benefits for the marine environment, there are indirect benefits. For example, contributing to stabilization of atmospheric CO_2 concentrations may lead to benefits for the global environment in mitigating:

.1 changes in sea surface temperatures;

.2 potential changes in salinity, wave conditions, and ocean circulation;

.3 decreases in sea ice cover;

.4 loss of wetlands and mangroves from sea level rise; and

.5 the extent and severity of weather-related events, storm impacts, and seawater intrusion into fresh water systems.

8 A considerable body of evidence and experience exists on CO_2 sequestration which leads to the conclusion that sequestration is technically feasible and makes use of established technologies, including sequestration technologies, technical mitigation options for CO_2 leakage and monitoring methods. The report of the 28th session of the Scientific Group noted that storage capacity, monitoring, suitability and acceptability would inevitably be site-specific. If properly sited and managed, the risk of these projects is expected to be low. Finally, the report stated that there are gaps in knowledge related to possible impacts on the marine environment and in technology, such as monitoring techniques of these impacts, and that it would be necessary to develop an assessment framework for evaluation and management of the potential risks to the marine environment, using established risk assessment approaches.

9 The Special Report on Carbon Dioxide Capture and Storage of the Intergovernmental Panel on Climate Change (IPCC SRCCS), published in 2005, and recent documents prepared under the auspices of OSPAR or others, give the ‘state of the art’ needed to fulfil the terms of reference of the SG Intersessional Technical Working Group on CO_2 Sequestration (LC 27/16, annex 6). It would be useful to consider other relevant studies undertaken by organizations such as IPCC, IEA GHG, and OSPAR and communicate with these organizations.

10 The IPCC SRCCS concluded that there is sufficient geological storage capacity to contribute to stabilization of CO_2 concentrations in the atmosphere. A significant portion of this capacity is in structures beneath the oceans, including areas where there has been exploration for oil and gas and where a good knowledge of sub-seabed geology exists. Storage sites will be selected and projects designed to permanently confine CO_2. IPCC SRCCS, Table 5.5, provides a summary of evidence for CO_2 retention and release rates based on:

.1 data from natural systems, including trapped accumulations of natural gas and CO_2, as well as oil;

.2 data from engineered systems, including natural gas storage, gas and CO_2 re-injection for pressure support, CO_2 or miscible hydrocarbon EOR, disposal of acid gases, and disposal of other fluids;

.3 data from natural systems, including trapped accumulations of natural gas and CO_2, as well as oil;

.4 fundamental physical, chemical and mechanical processes regarding the fate and transport of CO_2 in the subsurface;

.5 results from numerical models of CO_2 transport; and

.6 results from current geological storage projects.

11 CS-SSGS is a waste management option that should be considered within the context of Contracting Parties' approaches to mitigating greenhouse gas emissions. The "Risk Assessment and Management Framework for CS-SSGS", as developed, has not addressed, in detail, the waste prevention audit and the waste management options, which are requirements of Annex 2 to the London Protocol. As Contracting Parties were required to address these matters in the assessment of CS-SSGS, further consideration may therefore be necessary.

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ANNEX 3

RISK ASSESSMENT AND MANAGEMENT FRAMEWORK FOR CO_2 SEQUESTRATION IN SUB-SEABED GEOLOGICAL STRUCTURES (CS-SSGS)

Table of contents

0 INTRODUCTION AND SUMMARY

0.1 This Risk Assessment and Management Framework for CO_2 Sequestration in Sub-Seabed Geological Structures (CS-SSGS) is developed to ensure compatibility with Annex 2 to the London Protocol, identify relevant gaps in knowledge, and reach a view on the implications of CS-SSGS for the marine environment. This Framework aims to provide generic guidance to the Contracting Parties to the London Convention and Protocol, in order to:

.1 characterize the risks to the marine environment from CS-SSGS on a site-specific basis; and

.2 collect the necessary information to develop a management strategy to address uncertainties and any residual risks.

The Risk Assessment and Management Framework

0.2 The six stages of this Risk Assessment and Management Framework can be summarized as follows:

.1 ***Problem Formulation*** is a critical scoping step of risk assessment as it defines the bounds of the assessment, including the scenarios and pathways to be considered. The Framework is suitable for assessing and managing the potential risks to the marine environment;

.2 ***Site Selection and Characterization*** concerns the collection of data necessary for describing the physical, geological, chemical, and biological conditions at the site. These data are used for both site selection and the analyses conducted in various other elements of the Framework;

.3 ***Exposure Assessment*** is concerned with describing the movement of the CO_2 stream within geological structures and the marine environment. The processes and pathways for migration of CO_2 from geological storage reservoirs and leakage to the marine environment, during and after CO_2 injection, can be assessed. This can include additional substances mobilized by the CO_2 and displaced saline formation water. The processes involved in such migration behaviour will be governed by site-specific factors. The uncertainties associated with such an assessment can be identified;

.4 ***Effects Assessment*** assembles the information necessary to describe the response of receptors within the marine environment resulting from exposure to the CO_2 stream if leakage were to occur. The main effects of concern to such an assessment include effects on human health, marine resources, relevant biological communities, habitats, and ecological processes, and other legitimate uses of the sea. A qualitative assessment of environmental effects on the marine environment is currently possible using available data. Effects research would inform more quantitative assessments;

.5 ***Risk Characterization*** integrates the exposure and effects information to provide an estimate of the likelihood for adverse impacts. Risk characterization should be considered using site-specific information. Factors evaluated in a risk characterization may change over time given the operational status of the project and ongoing data collection used to update predictive models. The sources and level of uncertainty associated with a risk estimate will be a function of the data and modelling assumptions used. Given the long time-scales involved in CS-SSGS it will be useful to distinguish between processes relevant to characterizing risks in the near-term during the period of active operations and injection at a site and long-term processes operating after site closure. The time-scales over which records will need to be managed for such sites may be longer than for other waste materials covered by the London Convention; and

.6 ***Risk Management*** includes both monitoring during and after CO_2 injection, planning and mitigation actions. The health, safety and environmental risks of CS-SSGS will be comparable to the risks of such current activities as natural gas storage, enhanced oil recovery, and deep underground disposal of acid gas when risk management activities (including monitoring and mitigation of releases if they arise) are combined with appropriate site selection and a governing regulatory system.

1 PROBLEM FORMULATION

Scope of problem

1.1 Problem formulation is the scoping of a risk assessment and includes the collection of information that will be used to develop a site-specific conceptual model to direct a site-specific risk assessment. It is important to identify gaps and uncertainties at this stage.

1.2 The intent of CS-SSGS is to prevent release into the biosphere of substantial quantities of CO_2 derived from anthropogenic activities. The aim is to retain the CO_2 within these structures permanently.

1.3 CS-SSGS, for the purposes of climate change mitigation, is into geological strata at least several hundred meters below the layer of unconsolidated sediments on the seabed. Therefore, it should be stressed that the locations of disposal will differ from those of other operations currently permitted by the London Convention and Protocol and consequently the site selection and assessment considerations will also require a geological assessment. These current practices comprise the disposal, or dumping, of dredged material or other waste materials into the marine water column, surficial sediment or into the seabed. No current practice involves disposal or dumping into layers of the seabed greater than about 10 metres.

1.4 The sources of CO_2 considered here are those industrial activities currently releasing large quantities of CO_2 to the atmosphere. CO_2 injection streams may contain other substances derived from the source material. The actual composition of the injection streams intended for sequestration in the sub-seabed will therefore vary in their content of CO_2 and other substances depending on the nature of the source material and the methods used for CO_2 capture and liquefaction to super-critical temperatures and pressures. However, it must be stressed that none of these other substances will have been deliberately added to the CO_2 stream for the purposes of waste disposal.

1.5 Major issues to be addressed include:

.1 the suitability of deep geological reservoirs to retain the CO_2 reliably for long periods;

.2 the nature of the overburden to act as a barrier to prevent or retard upward migration of CO_2 should leakage occur;

.3 the nature of the marine environment above the site of CS-SSGS in relation to concerns with potential adverse effects of any CO_2 from the reservoir that succeeds in reaching it;

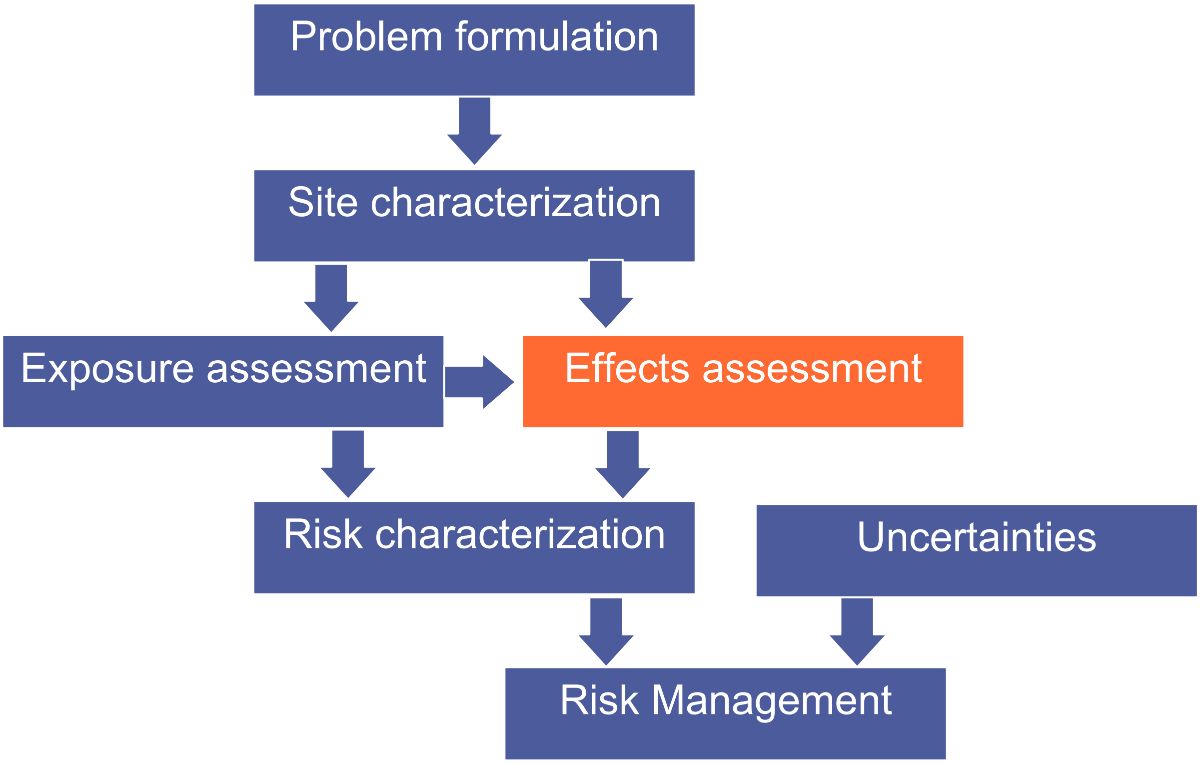
.4 the need for records associated with the authorization and licensing process, together with monitoring data, to be maintained for much longer periods than those associated with other authorized practices and indeed most other human activities. The longevity of monitoring activities and management response capabilities is also much longer than those required for other practices permitted under these instruments; and

.5 depending upon the depth of the water column into which leakage of CO_2 from the underlying sediments could potentially occur, differing exposure and effects regimes will be relevant. A primary cause for this relates to the specific gravity of CO_2 as a function of hydrostatic pressure in the marine water column. At shallower water depths (approximately < 2500 metres), the forms of CO_2 potentially released are buoyant in seawater. At greater depths, the forms of CO_2 can include components that are denser than the surrounding seawater and will tend to sink. The latter situations will impose a need to take account of differing exposure and effects conditions than those applicable to releases involving buoyant forms of CO_2.

1.6 The depths of water below which CS-SSGS is likely to be considered in the near future are generally less than 500 metres (*i.e.,* predominantly beneath continental shelves). This is sufficiently shallow such that the forms of CO_2 potentially escaping from the underlying sediments will have positive buoyancy. For this reason, CS-SSGS underlying deeper waters, such as geological structures under the pelagic ocean, is not further considered in the guidance provided here. Should interest in CS-SSGS develop at much greater depths than those in continental shelf and upper continental slope environments, this guidance will need to be revised to take account of other exposure and effects pathways.

Conceptual Model

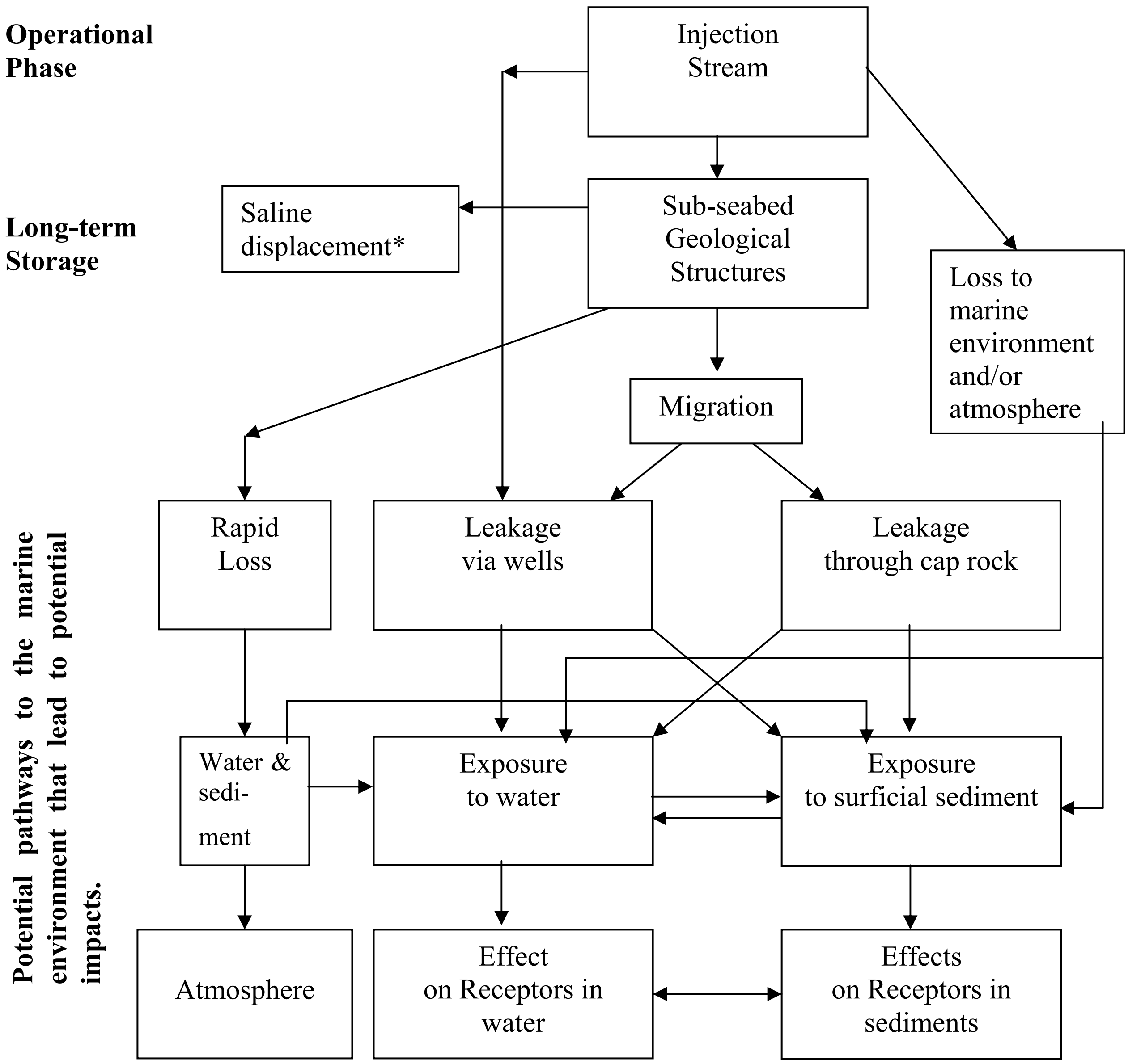
Figure1
Effects in a risk assessment framework



1.7 Generic conceptual models of potential environmental pathways and effects that are relevant to the consideration of the potential consequences of CO_2 release to the marine environment from CS-SSGS are shown in figures 1 and 2. It is important to point out that the problem formulation and, indeed, the Risk Assessment and Management Framework itself should be followed in an iterative manner rather than as a strictly sequential once-through process.

1.8 Issues of concern that are peculiar and additional to those already incorporated into the "Guidelines for the Assessment of Waste or Other Matter that May be Considered for Dumping"[i] under the London Protocol, also known as the "Generic Guidelines", are briefly discussed below.

Figure 2 - Conceptual model of potential environmental pathways and effects[5]



* Exposure and effects assessments of the displacement of saline water by injection streams may be required. The sites of these displacements into the marine environment can be at great distances from the injection site, depending on the geological circumstances.

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[5] It is important to point out that the problem formulation and, indeed, the Risk Assessment and Management Framework itself should be followed in an iterative manner rather than as a strictly sequential once-through process.

Potential migration or release of CO_2 into the marine environment

1.9 This comprises two aspects: first, potential releases during the operational phase of CS-SSGS; and, second, migration and releases of CO_2 from the sub-seabed geological structure following the injection process.

Potential Operational Releases

1.10 These would most likely result from major seal failure or disruption of the means of emplacement of the CO_2 in the geological structure *i.e.* the pipeline or means of insertion from a vessel and the injection well. Capped well locations are also potential sources of leakage and their potential is dependent upon well integrity and age. The probability of leakage through cap rock is unlikely with proper site characterization and selection, barring an unpredictable seismic event. However, if leakage does occur during this phase, then mitigation is likely to be possible e.g., by reducing reservoir pressure.

1.11 The physical effects associated with major releases of gaseous CO_2 are primarily the disturbance of unconsolidated bottom sediment caused by the flow and expansion of CO_2 as it passes through the upper sediment column and into the overlying water column. Associated with such events would also be turbulence and therefore increased vertical mixing in the water column. However, such disturbance would require a substantial and rapid release of gaseous phase CO_2 to cause a major disturbance. At the extreme, a substantial and rapid gas release at the seafloor could cause damage to the marine environment, interference with other legitimate uses of the sea, including fishing and maritime transport, with the potential for associated risks to human health.

1.12 In the event of more likely CO_2 release episodes, the CO_2 enriched stream could potentially contact the marine sediments and/or the water column. This contact could potentially alter the physiochemical nature of marine sediments, the surrounding boundary layer of marine waters, and/or the water column, e.g. depression of pH. The spatial and temporal nature of such a release, and the underlying nature of the surrounding hydrodynamics will determine the degree of any exposure in the water column. Short and long-term effects as well as population level effects and species-specific impacts need to be considered. Impact hypotheses derived from these potential impacts should influence monitoring and mitigation plans.

Potential Post-Injection Releases

1.13 These will be as for the potential operational releases in respect of leakages via a capped well and the cap rock but with the significant difference that it will apply over long periods of time. In addition, the capacity to mitigate is likely to be reduced as the infrastructure and associated resources would not be available. This implies that long-term precautionary measures need to be taken prior to closing the injection site.

2 SITE SELECTION AND CHARACTERIZATION

Introduction

2.1 Key goals for geological CO_2 storage site selection and characterization are to:

.1 assess how much CO_2 can be stored at a potential storage site;

.2 demonstrate that the site is capable of meeting required storage performance criteria; and

.3 establish a baseline for the management and monitoring of the CO_2 injection and storage.

2.2 Site characterization requires the collection of the wide variety of geological and environmental data that are needed to achieve these goals. Much of the data will necessarily be site-specific. Most data will be integrated into geological models that will be used to simulate and predict the performance of the site. These and related issues are considered below.

Different types of storage reservoirs and trapping mechanisms

2.3 So far oil or gas reservoirs and saline aquifers have been expected to have the largest potential for safe and long-term storage. A large part of the identified storage capacity is located offshore.

Oil and gas reservoirs

2.4 Oil and gas reservoirs can be used for CO_2 storage, both when the reservoir is depleted and when CO_2 is used for enhanced oil recovery (EOR). EOR falls outside the scope of this Framework. The existence of abandoned oil and gas wells within the relevant domain of the storage site provides potential avenues for leakage pathways. Since the capillary seal for oil and gas reservoirs has already proven its sealing integrity, the risk for leakage through these types of seals is considered most unlikely, provided that the seal has not been damaged during exploitation of gas or oil. There is a wealth of knowledge on geology and sealing potential of these formations and structures to facilitate the site selection and characterization. Additional information may be needed once a reservoir is selected for CS-SSGS.

Deep saline formations

2.5 Deep saline formations are geological formations or structures containing saline water. For such formations that have not been storing oil or gas, the verification of the integrity of the sealing rock is more challenging than for oil or gas fields. In some areas the geology of such formations is well documented, e.g., where oil and gas exploration take place, while in other areas such data will need to be collected and modelled in order to verify the formations capability of storing CO_2.

Other possible geological structures for CO_2 storage

2.6 Unminable coal beds, basalts, oil and gas shales, salt caverns and other geological formations and structures may also be considered for CO_2 storage. These structures have not been explicitly considered during the development of this Risk Assessment and Management Framework.

Trapping mechanisms

2.7 In the selection of appropriate sites, the different mechanisms retaining CO_2 underground is relevant. Driving forces, which could promote migration of CO_2 out of the reservoir, are the pressure increase caused by injection of CO_2 and the buoyancy due to the density of CO_2 which is lighter than brine. This density difference is about the same as the density difference between oil and brine. There are several mechanisms that are effective in preventing injected CO_2 from escaping from a reservoir. The most important one is the presence of a cap rock acting as an upper seal to prevent CO_2 flow out of the reservoir. This is relevant for both storage in oil and gas reservoirs and for deep saline aquifers.

2.8 Other trapping mechanisms include pore trapping of CO_2 (residual gas trapping), dissolution of CO_2 in brine and mineral trapping of CO_2.[ii] For well-selected, designed and managed geological storage sites, the vast majority of the CO_2 will gradually be immobilized by these trapping mechanisms. Because of these mechanisms, storage could become more secure over longer time frames (IPCC 2005).

Site selection process and site characterization

2.9 Important issues during the site screening and selection process for CO_2 storage may include:

.1 the storage capacity and injectivity of the formation;
.2 the storage integrity;
.3 the suitability of the vicinity and surrounding area; and
.4 potential migration and leakage pathways over time and potential effects of leakage of CO_2.

2.10 The table shown in Appendix 1 to this Framework outlines some of the information that may facilitate the selection and characterization of sites for CS-SSGS. This table shows possible considerations rather than formal requirements. A storage site and its surroundings, including the overlaying sediment and water column, need to be characterized in terms of geology, hydrogeology, geochemistry, geomechanics and biology. A significant amount of data may be needed to establish both the feasibility of a CO_2 injection and also to provide evidence of the integrity of the site over the time-scale relevant for the sequestration issue. The site selection will typically include a reservoir simulation to assess a potential storage site, e.g., by a three-dimensional geological model. Relevant factors for the assessment of the suitability of geological structures for CO_2 storage in respect of both the protection of the marine environment and climate-change mitigation include characterization of the reservoir, the cap rock, geological stability, possible leakage-path routes and trapping mechanisms.

2.11 Storage site requirements depend greatly upon the above-described trapping mechanisms. The type of storage, and data availability and quality vary greatly between each of these options.

2.12 Taking into account the potential consequences to the environment in case CO_2 leaks to the sea floor, the characterization and selection of sites should take into consideration the proximity of the site to sensitive or endangered habitats and species, including natural resources such as fish. Other use of the area such as oil and gas exploration and exploitation and fisheries may also be taken into consideration.

2.13 The sources of information will vary, but analysis will mainly rely on the sampling of well cores (both in the reservoir and the overlaying formations), the acquisition of well logs, seismic surveys, and also data available from existing wells or fields in neighbouring locations.

2.14 This information is useful for the site selection and characterization, and thus establishes a baseline before the site is used for CO_2 storage (the pre-injection stage). It should also be noted that, as the project moves into the injection and the post injection stages, this baseline information should be used for development of a monitoring strategy and evaluation of the results of the monitoring.

Conclusions on site selection and characterization

2.15 Important issues during the site screening and selection process for CS-SSGS may include:

.1 the storage capacity and injectivity of the formation;
.2 the storage integrity;
.3 the suitability of the surrounding area; and
.4 potential migration and leakage pathways over time and potential effects of leakage of CO_2.

2.16 There is significant potential for geological storage in structures beneath the oceans. Oil and gas reservoirs and saline formations are expected to have the largest potential to accommodate safe, long-term storage. The aim is to retain CO_2 permanently. Because of the various trapping mechanisms, storage may, in some cases, become more secure over time.

2.17 Criteria for site selection, management procedures and contingency planning could be seen as one means of guaranteeing the high environmental integrity of CS-SSGS. The "Generic Guidelines" contain guidance for site selection and characterization on a generic level. Specific guidance, or a framework for the assessment of potential storage sites, would be useful. Relevant factors may include characterization of the reservoir, the cap rock-trapping mechanisms, geological stability, possible leakage-path routes and ecosystem characteristics. It would be useful to develop more specific guidance related to CO_2 storage in geological structures and formations.

3 EXPOSURE ASSESSMENT

3.1 Exposure assessment informs the characterization of effects and provides an input into the wider risk characterization and risk mitigation. Information gathered at this stage should be appropriately recorded and documented.

Chemical and physical characterization of the CO_2 stream, including other substances

3.2 Characterization of the injection stream is essential. The captured CO_2 stream may contain other substances that could have practical impacts on CO_2 transport and storage systems and also potential health, safety and environmental impacts. Other substances in the CO_2 stream can be identified and quantified and uncertainties identified, for the purpose of gathering information required for the effects assessment (see Chapter 4) and wider risk assessment and management (Chapters 5 and 6). Particular attention should be given to those substances which are known to have significant effects on the marine environment as identified through the use of the Action List under Annex 2 to the London Protocol. The composition of the injection stream should be consistent with the primary purpose of mitigating greenhouse gas emissions.

3.3 The types and concentrations of other substances vary depending mainly on the basic process (e.g., gasification, combustion, natural gas cleanup), source material, and type of capture process. As an example, the following table from the IPCC SRCCS[iii] demonstrates the type and magnitude of other substances which may be found in CO_2 streams from power plants. Note that these substances may be different for CO_2 streams from other sources such as refineries, steel plant, etc.

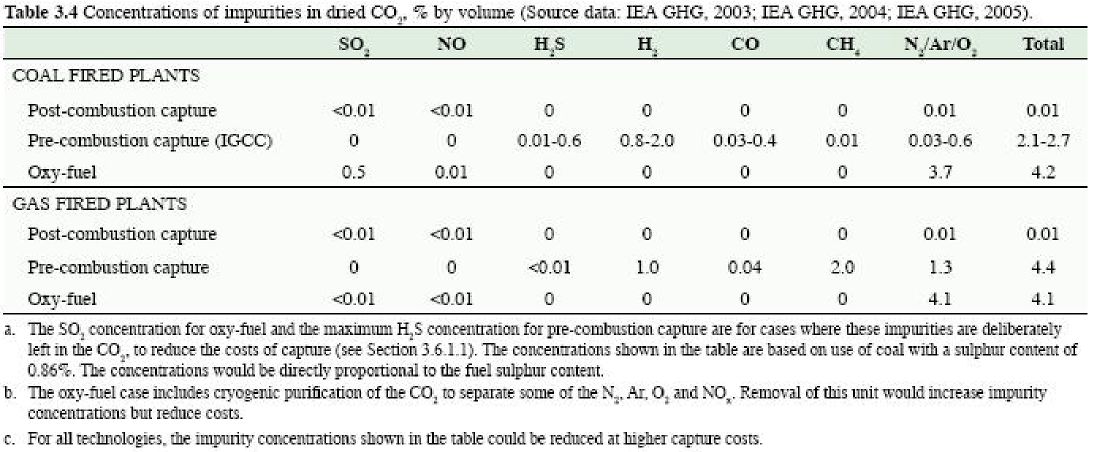

Table 3.4 Concentrations of impurities in dried CO_2, % by volume (Source data: IEA GHG, 2003; IEA GHG, 2004; IEA GHG, 2005).

	SO_2	NO	H_2S	H_2	CO	CH_4	$N_2/Ar/O_2$	Total
COAL FIRED PLANTS								
Post-combustion capture	<0.01	<0.01	0	0	0	0	0.01	0.01
Pre-combustion capture (IGCC)	0	0	0.01-0.6	0.8-2.0	0.03-0.4	0.01	0.03-0.6	2.1-2.7
Oxy-fuel	0.5	0.01	0	0	0	0	3.7	4.2
GAS FIRED PLANTS								
Post-combustion capture	<0.01	<0.01	0	0	0	0	0.01	0.01
Pre-combustion capture	0	0	<0.01	1.0	0.04	2.0	1.3	4.4
Oxy-fuel	<0.01	<0.01	0	0	0	0	4.1	4.1

a. The SO_2 concentration for oxy-fuel and the maximum H_2S concentration for pre-combustion capture are for cases where these impurities are deliberately left in the CO_2, to reduce the costs of capture (see Section 3.6.1.1). The concentrations shown in the table are based on use of coal with a sulphur content of 0.86%. The concentrations would be directly proportional to the fuel sulphur content.

b. The oxy-fuel case includes cryogenic purification of the CO_2 to separate some of the N_2, Ar, O_2 and NO_x. Removal of this unit would increase impurity concentrations but reduce costs.

c. For all technologies, the impurity concentrations shown in the table could be reduced at higher capture costs.

3.4 The IPCC SRCCS states that the fate in the capture plant of other substances that may occur in the feed gas (such as heavy metals) is not well known, and therefore attention should be paid to identifying these substances in the injection stream.

Exposure processes and pathways from transport and injection equipment

3.5 Processes and pathways for leakage of CO_2 to the marine environment and the atmosphere from transport and injection equipment should be addressed, and uncertainties identified. There are potential leakage possibilities along the CS-SSGS chain from the capture site, via compression, pipeline transportation and injection facilities, to the final storage reservoir. These will be site-specific. Potential release pathways to the water column from equipment during the injection phase can be from:

.1 the connecting pipeline from the CO_2 recovery plant to the storage site;
.2 the sub-sea template and injection well(s) (if no surface installation); and
.3 the platform injection well or CO_2 riser, pipeline and injection well.

3.6 The IPCC SRCCS indicates that, at the storage site, adequate plans need to be in place for dealing with excess CO_2 if the injection well(s) need to be shut in. Options include having a backup injection well or methods to safely vent the CO_2 to the atmosphere. Proper maintenance of site facilities and injection wells is necessary to avoid leakage and well failures. For injection through old wells, key factors include the mechanical condition of the well, the quality of cement and well maintenance. All materials used in injection wells should be designed to anticipate peak volume, pressure and temperature. In the case of gas containing free water, use of corrosion-resistant materials is essential. There are several analogues from offshore transport and injection of hydrocarbon gas and onshore CO_2 injection projects that can provide data for risk assessment.

Exposure processes and pathways from geological storage reservoirs

3.7 Processes and pathways for migration of CO_2 from geological storage reservoirs and leakage to the marine environment, during and after CO_2 injection, can be assessed. This includes additional substances mobilized by the CO_2 and displaced saline formation water. Such assessments should be site-specific. Attention should be paid to both long-term and short-term processes.

3.8 Processes to be considered should include that free gaseous CO_2 and supercritical CO_2 are less dense than water or brine under typical geological conditions, so tend to rise towards the seabed. For example, if the reservoir pressure is high and leakage pathways exist, migration of free and dissolved CO_2 out of the storage reservoir may result. Low-pH formation water resulting from the dissolution of CO_2 may promote corrosion of well-construction and plugging materials.

3.9 The IPCC SRCCS[iv] indicates that potential migration and release pathways from geological reservoirs include:

.1 through the pore system in low-permeability cap rocks if the capillary entry pressure at which CO_2 may enter the cap rock is exceeded;
.2 if the cap rock is locally absent;
.3 through faults or other fractures in the cap rock; and
.4 through inadequately completed and/or abandoned wells.

3.10 Additional migration and release pathways may include:

.1 lateral migration of free or dissolved CO_2 along the reservoir rock, e.g., if a storage structure is overfilled; and
.2 degradation of the cap rock or wells by reaction with acidic formation waters.

3.11 Site characterization and numerical simulation of CO_2 injection and the long-term fate of the stored CO_2 may be appropriate to help identify potential migration pathways and leakage pathways and flux rates.

Water/Biosphere – exposure processes and pathways

3.12 The transport, mixing processes and rates of leakage of any CO_2 to the seabed sediments and water column should be assessed. Leakage of free and dissolved CO_2 and additional substances being mobilized by the CO_2, for example saline formation water (as per "saline displacement" identified in Figure 2 in Chapter 1 of this Framework), should be considered.

Likelihood of exposure

3.13 The probabilities of the exposure processes identified in the Chapters 2 and 3 of this Framework may be assessed using appropriate techniques, including numerical modelling and simulation tools. Uncertainties should be identified, for example completeness of the simulation models and sensitivity analysis.

3.14 Data from existing CO_2 storage projects contributes to improving the quality of long-term performance predictions and the knowledge base is growing. The IPCC SRCCS[v] concluded that, assuming that sites are well selected, designed, operated and appropriately monitored, the balance of available evidence indicates: it is likely that the fraction of stored CO_2 retained is more than 99% over the first 1000 years.

Scale of exposure

3.15 Assessment of the amount of CO_2 and additional substances being mobilized by the CO_2 and the scale of spatial and temporal fluxes should be undertaken using an appropriate numerical modelling and simulation tool described in Chapter 5 of this Framework. Uncertainties should be identified (see the previous sections within this Chapter).

3.16 The IPCC SRCCS[vi] indicates that simulations of CO_2 in large-scale storage projects suggest that the movement of CO_2 through the subsurface will be slow, and its examination of the possible exposure processes suggest that they would result in leakage over longer-time periods. Evidence also suggests that exposure processes will result in localized emissions to the biosphere. However, as each site is different, the possible quantities of CO_2 and the scale of spatial and temporal fluxes, e.g., CO_2 concentration in the water column should be assessed on a site-specific basis, for the purposes of the Effects Assessment in Chapter 4 of this Framework.

Uncertainties and data gaps

3.17 The following gaps in information, knowledge and experience were identified:

.1 knowledge of expected composition of injection streams from CO_2-generation processes;

.2 understanding the behaviour and interaction of other substances which may be in the injection stream once in the geological and marine environment;

.3 development and application of simulation models for probability of exposure;

.4 understanding existing and abandoned well integrity and leakage processes; and

.5 understanding how other substances may be mobilized by the CO_2.

Conclusions on exposure assessment

3.18 An exposure assessment should be undertaken to inform the effects characterization and form part of the wider risk characterization and risk mitigation. The information gathered should be appropriately recorded and documented.

3.19 Characterization of the injection stream is essential. The types and concentrations of other substances vary depending mainly on the basic process (e.g., gasification, combustion, natural gas cleanup), source material, and type of capture process.

3.20 Processes and pathways for migration of CO_2 from geological storage reservoirs and leakage to the marine environment and the atmosphere, during and after CO_2 injection, should be assessed. This should include additional substances mobilized by the CO_2 and displaced saline formation water. These should be site-specific. The uncertainties should be identified.

3.21 The transport, mixing processes and rates of leakage of any CO_2 (and other substances mobilized by CO_2) to the seabed sediments and water column should be assessed.

3.22 The probabilities of the exposure processes may be assessed using appropriate numerical modelling and simulation tools. Assessment of the amount of CO_2 and the scale of spatial and temporal fluxes should be undertaken using an appropriate numerical modelling and simulation tool.

4 EFFECTS ASSESSMENT

Introduction

4.1 Assessment of the potential effects should lead to a concise statement of the expected consequences of CS-SSGS. It provides input for deciding whether to approve or reject the proposed waste management option, to inform site selection, monitoring to verify the hypothesis, and also management measures and for defining environmental monitoring requirements.

4.2 A sub-seabed geological storage site is not intended to leak to the marine environment, therefore the following null-hypothesis is proposed:

> *No impact on human health, the marine environment and other legitimate uses of the sea will occur.*

4.3 Potential risks to humans and ecosystems from geological storage may arise from leaking injection and abandoned wells, leakage across faults or ineffective seals. Leakage from offshore geological storage sites may pose a hazard to benthic and pelagic ecosystems as well as other legitimate uses of the sea as the CO_2 moves from deep geological structures through benthic sediments into the ocean[vii].

Sensitivity of species, communities, habitats and processes

4.4 This section highlights the sensitivity of species, communities etc., for CO_2 exposure, data requirements and temporal and spatial issues.

4.5 The main effects to consider in relation to the leakage of CO_2 are those that result from the increase of CO_2 concentration in the ambient water and sediments. As discussed in LC/SG CO2 1/INF.2 (page 9), the effects of CO_2 released to water bodies depend upon the magnitude and rate of release[viii], the chemical buffer capacity of the water body, and transport and dispersion processes. Changes in pH are directly related to the partial pressure of CO_2 and the chemical buffer capacity of the water. High CO_2 levels in water may impair respiration in fish and cause lowering of pH in animal body fluids (*acidosis)*, increased concentrations of CO_2 in body fluids (*hypercapnia*) and impairment of oxygen transport in animals (*asphyxiation*). The changes in ocean chemistry caused by CO_2 leakage may have profound effect on calcareous organisms such as corals, shellfish, and specific groups of phytoplankton. Effects of *disturbed calcification rates* may include reduced levels of growth and reproduction, as well as increased mortality rates.

4.6 Effects of exposure to other contaminants in the CO_2 stream could be assessed as well. Also, changes of pH in sediments due to CO_2 might have effects on metal speciation e.g., mobilising trace metals and other compounds to a higher extent of bioavailability[ix]. This may lead to direct toxic effects and/or accumulation in the food chain. Contracting Parties should refer to Chapter 5 of this Framework and the Action List under Annex 2 to the Protocol for additional information on potential substances of concern. The effects of displacement of saline water should be included in the effects assessment as well.

4.7 The evaluation of human effects and ecosystem sensitivity is addressed in paragraphs 6.7 through 6.12 of the "Generic Guidelines". General information on Assessment of Potential Effects can be found in Chapter 7 of the Generic Guidelines. The OSPAR report[x] distributed as LC/SG-CO2 1/INF.3 contains information on ecosystem sensitivity.

Temporal and spatial issues

4.8 Stored CO_2 and any accompanying substances may affect the environment with which it comes into contact through different exposure scenarios. Releases may occur on a variety of temporal and spatial scales, ranging from local sudden releases up to slow leakage in a wide area. The impacts will likely differ accordingly.

4.9 The worst-case scenario is not necessarily defined by the rate of CO_2 release but rather by the total amount of CO_2 with which the ecosystem comes into contact. The spatial extent of the waters with increased CO_2 content and decreased pH will depend on the amount of CO_2 released and also on the prevailing environmental conditions at the ocean bottom as these can significantly influence the fate and behaviour of the released CO_2. For example, stratification may trap CO_2-enriched water at the bottom of the ocean.

4.10 The resilience of marine ecosystems remains largely unknown. Disturbance, re-colonization and community recovery in the deep ocean follows similar patterns to those in shallow waters but on much longer time-scales (several years compared to weeks or months in shallow waters). Prediction of future changes in ecosystem dynamics, structure and functioning benefits from data on sub-lethal effects over the entire life history of organisms.

Human health and other legitimate uses of the sea

4.11 In addition to effects on the environment, the effects assessment evaluates the potential effects on human health (including food chain effects), marine resources, amenities and other legitimate uses of the sea. This might especially be relevant when large amounts of CO_2 may reach the sea surface, which consequently may endanger human life and other legitimate uses of the sea.

Uncertainties and data gaps

4.12 Effect data from exposure to increased CO_2 concentrations are available, but are mostly scarce, scattered and limited in detail[xi]. Existing field data are mainly limited to deep-sea situations (for ocean storage of CO_2). Specific data are available on the effects of ocean acidification due to increased atmospheric CO_2 concentrations (LC/SG-CO2 1/INF.3)[xii]. With regard to the available effect data, considerations include:

.1 identification of effects at the level of both the individual species (physiological) and the ecosystem;

.2 performance of field studies of ecosystem consequences;

.3 studies of the response of representative species to various doses of added CO_2;

.4 studies that are longer in duration (intervals greater than the duration of a reproduction cycle or the lifespan of an individual) and larger in scale than currently performed[xiii];

.5 because CO_2 effects are generally larger than pH effects only, data generated using the realistic mechanism of increasing CO_2 concentrations under marine conditions, not mimicking pH effect using acids, are preferred. Ambient ocean conditions (e.g., temperature, pressure) should be considered;

.6 preferably, data acquisition should be carried out to include the effect on vulnerable life stages for a range of representative species (including microbial communities) found at the site, ensuring that ecosystem structure and functioning is represented;

.7 effects of CO_2 on physiological and ecological processes, including abundance and biodiversity as well as biological/geological/chemical cycles, are relevant;

.8 where ecosystem models are available and validated, the effects on species, communities, habitats and processes could be considered in the context of these models;

.9 determination of a quantitative relation between exposure concentrations and the related effects for a quantitative assessment of effects; and

.10 the inclusion of receptors - for which sensitivity is not quantifiable - in a monitoring programme, in the event of a leakage.

Conclusions on effects assessment

4.13 Although the intention of the process of CS-SSGS is no leakage, effects assessment contributes to informing site selection, monitoring to verify the impact hypothesis, and management measures.

4.14 While the effect mechanisms of release of CO_2 from CS-SSGS may differ from the disposal of other controlled materials, the possible impacts can be identified and assessed within the framework of Annex 2 to the London Protocol.

4.15 The main considerations in relation to the leakage of CO_2 should be the effects of CO_2 concentrations on human health, marine resources, sensitivity of species, communities, habitats and processes, and other legitimate uses of the sea.

4.16 Effects of exposure to other contaminants in the CO_2 stream should be included in the assessment.

4.17 Metals and other substances mobilized in a decreased pH environment should be included in the assessment.

4.18 A qualitative assessment of environmental effects is possible, based on available data, but further research would inform quantitative assessments.

5 RISK CHARACTERIZATION

Introduction

5.1 Risk characterization is the final step in the risk assessment process which determines the likelihood and severity of impacts on the marine environment. It is used to establish relationships between stressors, effects, and ecological entities and provide an overall assessment of the potential hazards associated with an activity. The following basic steps are associated with risk characterization:

.1 estimating the risk posed to the receptors (e.g., ecosystems, human health, etc.) and the assessment endpoints identified in the problem formulation in Chapter 1;

.2 describing the risk estimate in the context of the significance of any adverse effects and the lines of evidence supporting their likelihood;

.3 identifying and summarizing the uncertainties, assumptions, and qualifiers in the risk assessment; and

.4 reporting the conclusions.

Risk Characterization for CS-SSGS

Overview

5.2 Risk characterization for CS-SSGS should be based on site-specific considerations of the potential exposure pathways, probabilities of leakage, and effects on the marine environment, human health, and other legitimate uses of the sea, as described in the previous chapters. It will be important to define the nature, temporal and spatial scales and duration of expected impacts.

5.3 Given the time-scales associated with CS-SSGS, it would be useful to characterize the risks at different stages of a project. The risks during injection and in the near-term (e.g., decades) may be different than the longer-term risks (e.g., over centuries to millennia) depending on site-specific considerations. In the injection phase, consideration should be given to risks such as the buoyant behaviour of CO_2, the pressure build-up in the reservoir, the quality of the seal and the well completion. Particular attention should be paid to integrity of the wells. Over the longer term, the risk assessment should also address any change in the integrity of the seal and of the plugs in the abandoned wells and might include the effects of CO_2 dissolution and mineralization.

5.4 When evaluating the spatial aspects of risk characterization, various factors are relevant to the potential area impacted, including the injection volumes and geological characteristics of the storage reservoir. In order to conduct an appropriate risk characterization, the potential spatial extent of the impacts should be estimated using models or other analytical tools.

5.5 A thorough site characterization (as discussed above) will be critical for the risk characterization which will also be closely linked to the development of a sound monitoring plan.

5.6 It would also be useful to update the risk characterization based on collection of new field data and/or performance assessment data.

Methods

5.7 Well-established methods exist for characterizing the risks of industrial injection operations. Diverse methods for assessing the long-term passive storage phase are being developed, building partly on the experience from hazardous and nuclear waste management. These models can either be simple box models or very detailed process models. In general, the risk assessment method comprises the following activities: identification of risks and underlying mechanisms, building scenarios describing possible future evolution or state of the site, developing dedicated models for the critical scenarios and applying the models in the assessment proper. The assessments can be performed in a probabilistic manner that quantifies the uncertainties connected with CO_2 storage or they can be executed in a deterministic way following a conservative approach. Existing experience in reservoir modelling is applicable to risk characterization. Several techniques are applied to address and/or quantify the uncertainties like Monte Carlo simulation[6], fault tree analysis and expert judgement. Natural and industrial analogues present suitable opportunities for testing the risk assessment models. These models could be integrated with effects assessment models to provide a comprehensive risk characterization.

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[6] See the Glossary in Appendix 3 to this report for an explanation.

Uncertainties and data gaps

5.8 Uncertainty analysis is important for the different stages of the assessment framework. Uncertainty can be constrained by the input of monitoring and field test data. Uncertainty will arise from any limitations to the static geological model and from the predictive models, as well as from the environmental effects assessment.

5.9 Research needs should be evaluated on a case-by-case basis and it will be necessary to gain data and experience in the field to validate the risk characterization. However, there are broad areas of research that would usefully assist future decision-making. Many of these areas are identified in the IPCC SRCCS:

.1 additional knowledge of the long-term behaviour and impact of CO_2 on reservoir fluids and rocks;

.2 long-term integrity of wells;

.3 the effects of CO_2 leakage on marine ecosystems;

.4 the potential for displaced brines and the effects; and

.5 the fate of other substances in the CO_2 stream and their effects.

Implications of risk characterization for Annex 2 to the Protocol

Impact Hypothesis

5.10 Annex 2 to the Protocol requires the development of an “Impact Hypothesis” - a concise statement of the expected consequences of disposal, which is based on an assessment of potential effects. It provides the basis for deciding whether to approve or reject the proposed disposal option and for defining environmental monitoring requirements. There are some key pieces of information identified in Annex 2 and the Generic Guidelines that are relevant to CS-SSGS:

.1 waste characteristics;
.2 conditions at the proposed dump-site(s);
.3 fluxes and proposed disposal techniques and the potential effects on human health, living resources, amenities and other legitimate uses of the sea;
.4 the nature, temporal and spatial scales and duration of expected impacts; and
.5 the potential impacts on amenities, sensitive areas, habitat, migratory patterns and marketability of resources and other uses of the sea including: fishing, navigation, engineering uses, areas of special concern and value, and traditional uses of the sea.

5.11 The Generic Guidelines contain several general statements regarding development and application of the Impact Hypothesis that are also relevant to CS-SSGS:

.1 the evaluation should be as comprehensive as possible, but it must be recognized that even the most comprehensive impact hypotheses may not address all possible scenarios such as unanticipated impacts;

.2 it would be essential to determine "where" and "when" the impacts can be expected;

.3 the expected consequences should be described in terms of affected habitats, processes, species, communities and uses;

.4 the monitoring programme should be linked directly to the hypotheses and serve as a feedback mechanism to verify the predictions and review the adequacy of management measures applied; and

.5 it is important to identify the sources and consequences of uncertainty.

Considerations for permitting decisions under the Protocol

5.12 Although the specific requirements of individual dumping permits will depend on a number of considerations and could be very detailed, there are some basic components that would be important for making permit decisions:

.1 basic documentation;

  .1 purpose of the permit;
  .2 types, amounts, and source of CO_2 stream;
  .3 the location of the site; and
  .4 the associated CO_2 transport and injection infrastructure;

.2 an adequate geological and hydro-geological site characterization;

.3 an assessment of the potential for leakage and associated impacts at the storage site;

.4 a suitable risk management plan including monitoring (both operational and long-term) and ability to apply mitigation (remediation) approaches, if necessary; and

.5 record keeping and periodic reporting requirements.

Conclusions on risk characterization

5.13 Risk characterization should be considered using site-specific information, but common guidelines would provide a useful framework.

5.14 Factors evaluated in a risk characterization may change over time given the operational status of the project and ongoing data collection used to update predictive models.

5.15 Sources and magnitude of uncertainty will be a function of the data and modelling assumptions used.

6 RISK MANAGEMENT

6.1 While CS-SSGS aims to isolate CO_2 from the biosphere and atmosphere permanently, risk management procedures are necessary to maximize the intended isolation and to minimize the effects of possible releases of CO_2.

6.2 Risk management is a structured process that begins with identifying and quantifying the risks associated with a given process, modifies the process to minimize risk and implements appropriate monitoring and intervention strategies to manage remaining risk. In the context of CS-SSGS, risk management consists of careful site selection, monitoring to provide assurance that storage is proceeding as expected and to provide early warning of CO_2 migration out of storage, effective regulatory oversight, and implementation of remedial measures to eliminate or limit the impacts of leakage.

6.3 Chapter 2 of this Framework on Site Selection and Characterization contains a list of elements that may be used for characterizing potential storage sites. This chapter provides a list of elements which are critical to risk management.

Prevention of CO_2 escape into the marine environment

6.4 Because the physical state of injected CO_2 will be supercritical and thus be similar to the physical state of water, the OGP Guidelines[xiv] and those published by OSPAR[xv] are largely applicable to managing CS-SSGS in an environmentally safe manner. The probability of cap rock fracture is low if pressure exerted by injected CO_2 is not allowed to exceed pressures known to be sustainable by the cap. For injection into exhausted oil or gas wells, the required geological data is largely available. For injection into saline aquifers or for other types of geological storage, the information may need to be obtained. The probability of CO_2 escaping through failure of the integrity of the injection well is low if the well is lined with materials known to withstand the acidity of carbonic acid which may be formed at the point of injection.

6.5 The general and specific information needs for risk management of injection sites for CS-SSGS are outlined in Appendix 2 to this Framework.

Well design and construction

6.6 The design and construction of an injection well are key factors in achieving the CO_2 injection objective. The well design and construction should account for operating conditions (pressure, fluid composition and acidity, duration etc.) and address identified potential well failure scenarios. The OGP Guidelines list the elements that need to be considered.

The spatial zone to be characterized

6.8 The maximum expected extent to which CO_2 is likely to migrate in the reservoir defines the zone to be characterized for risk management. To determine the confinement zone, the following factors, among others, will assist in the definition of the geographic volume to be reviewed:

.1 regional and local geology;
.2 regional stratigraphy;

.3 regional structure;
.4 regional hydro-geological conditions;
.5 seismic history;
.6 injection and confinement zone properties;
.7 hydrology of underground sources of potable and/or irrigation water if present/relevant;
.8 flow properties of the injection layer; and
.9 determination of the vertical hydraulic gradient.

6.9 Collection of this information in areas where there has been no previous hydrocarbon exploration or production is even more critical.

Reservoir flow and fracture propagation prediction

6.10 Predictive modeling of CO_2 injection should include both flow (reservoir) simulation and injection well fracturing and fracture propagation. These will establish the fate of the injected CO_2 and provide the operator with an integrated knowledge sufficient to manage the injection process in an environmentally protective manner. The modeling should provide predictions during the operational injection period and an assessment of the residual pressure fields after shut-in of the injection well.

6.11 Modeling should be updated in the light of monitoring results.

Process monitoring and control

6.12 Essential elements of process monitoring and control include:

.1 the injection rate;
.2 continuous pressure monitoring;
.3 injectivity and fall-off testing;
.4 the properties of the injected fluid (including temperature and solid content, the presence of substances other than CO_2 and the phase of CO_2); and
.5 mechanical integrity.

While not essential, if observation wells are available they can provide useful information.

Operational Issues

6.13 Contingency planning is an integral part of a CO_2 injection operation. Potential failure modes should be evaluated at the planning stage along with the necessary remedial actions that might be taken. Strategies such as transporting CO_2 to other parts of the same reservoir or to different storage sites or venting should be available. Examples of potential failures include:

.1 pressure build-up;
.2 confinement problems (breach to casing or cement around the casing); and
.3 mechanical complications (e.g., corrosion, erosion, failures of wellhead, etc).

Prevention of CO_2 escape from formations following decommissioning

6.14 It is anticipated that precautions taken after an injection formation has been filled to capacity will be similar to those used for oil and gas wells and by acid-gas disposal wells under which the wells are isolated from all surrounding permeable layers. Special care should be taken to use sealing plugs and cement that are resistant to degradation from carbonic acid.

6.15 Because the aim of CS-SSGS is to store CO_2 permanently, it will be necessary to archive documentation so that future generations are informed of the existence of the CO_2 reservoir and its history. This includes keeping records of the authorization and licensing process, together with data of long-term monitoring and management response capabilities.

Mitigation of CO_2 escaping from the formation

6.16 If appropriate, mitigation may begin as soon as CO_2 is known or suspected to have migrated from the formation. The need for mitigation is determined by national authorities on the basis of the likelihood that CO_2 will reach living marine or water resources and the extent of possible damage to those resources. Procedures for mitigating leaks of CO_2 have been reviewed in IPCC SRCCS. Release of CO_2 from an injection site can occur during or after the injection phase. The most likely avenues for unintended releases include:

.1 the injection well, possibly due to overpressure;
.2 other abandoned or active wells;
.3 areas where permeable rock reaches the surface of the seabed (e.g. spill points); and
.4 fractures of or high permeability zones within the cap rock.

6.17 Methods for remediation of these releases are analogous to techniques used in the oil and gas industry. These are described in Table 5.7 of IPCC SRCCS.

6.18 If leakage occurs through an active or abandoned well, mitigation methods may include:

.1 recapping wells or repairing faults in cement between rock and casings; and
.2 drilling intersecting wells followed by controlling the release with heavy mud and then recapping.

6.19 If leakage occurs through faults or fractures, mitigation methods may include:

.1 lowering the injection pressure or the well pressure by removing water or other fluids;
.2 halting the injection until the project is stabilized;
.3 transferring CO_2 to a more suitable reservoir; and
.4 plugging the pathway by injecting sealing material.

Monitoring migration of CO_2 within and above the reservoir

6.20 Techniques for monitoring stored CO_2 have been described in two IPCC documents: the IPCC SRCCS (IPCC, 2005) and the draft "Guidelines for National Gas Inventories"[xvi] (IPCC, 2006). Baseline information is required on the geological structures within and above the reservoir so that the signal produced by stored CO_2 can be distinguished from the natural system. Seismic methods have already been shown to work for monitoring oil and gas reservoirs but such methods may not be applicable to CO_2 storage in all settings. If seismic methods are used, careful consideration should be given to the effects on marine organisms of propagating seismic signals through the water column and seafloor.

6.21 Monitoring of CO_2 migration has four elements:

.1 performance monitoring (sometimes referred to as testing the Impact Hypothesis) which measures how well injected CO_2 is retained within the intended geologic formation;

.2 monitoring the geological layers above the reservoir to detect and measure migration of CO_2 out of the intended reservoir;

.3 monitoring the seafloor and overlaying water to detect and measure leakage of CO_2 into the marine environment. In this context special attention should be given to abandoned wells that intersect the storage reservoir; and

.4 monitoring benthic communities to detect and measure effects of leaking CO_2 on marine organisms.

6.22 The same techniques chosen for monitoring performance apply to monitoring geological layers above the reservoir. Until migration of CO_2 above the reservoir is detected and seen to possibly extend to the seafloor, monitoring the seafloor and overlaying water for leaking CO_2 may not be necessary. Similarly, until CO_2 is known to be leaking into the marine environment, biological monitoring may not be necessary.

Monitoring CO_2 migration after the well is decommissioned

6.23 Long-term monitoring can be accomplished with the same suite of technologies used during the injection phase. This includes keeping records of the authorization and licensing process, together with data of long-term monitoring and management response capabilities. However, new and more efficient monitoring technologies are likely to evolve. Methods chosen for monitoring should not compromise the integrity of a sealed formation. As confidence grows that CO_2 is not migrating from the reservoir, the frequency of measurement can be decreased.

Uncertainties and data gaps

6.24 Although a well-developed body of knowledge exists in the oil and gas industry for leak/release mitigation, more experience is required with mitigation of CO_2 releases from geologic reservoirs. This experience may be necessary to confirm the similarities of behaviour between oil and gas operations and CO_2 injection sites, or it may be necessary to determine special procedures that are required for handling CO_2 in these situations. The frequency and precision of monitoring during mitigation activities will likely need to increase to ensure minimum losses of CO_2 during the process. It may also be necessary to develop research programs at existing CO_2 injection sites to develop general guidelines for leak/release mitigation activities. These research activities may also explore new mitigation techniques that have not previously been examined in the oil and gas industry.

7 OVERALL CONCLUSIONS AND IMPLICATIONS

Conclusions

7.1 Ocean acidification and other global effects on the marine environment caused by elevated emissions of CO_2 are a cause of serious concern. Mitigation of these impacts necessitates a portfolio of options to reduce levels of atmospheric CO_2. As one such option, CS-SSGS is considered to be technically feasible, using established technologies.

7.2 The benefits of CS-SSGS have the potential to make a substantial contribution to reducing CO_2 emissions to the atmosphere, thus preventing these emissions from being absorbed into the oceans and providing mitigation of ocean CO_2, carbonate and pH change, effects on sensitive biological systems and nutrient availability and cycles. The potential risks posed by CS-SSGS are focused primarily at the local scale and include the potential for impacts on the marine environment in proximity to the receiving reservoir.

7.3 CS-SSGS is a waste management option to be considered within the context of Contracting Parties' approaches to mitigating greenhouse gas emissions[7].

7.4 CO_2 injection streams may contain other substances derived from the source material. The actual composition of the injection streams intended for sequestration in the sub-seabed will therefore vary in their content of CO_2 and other substances depending on the nature of the source material and the methods used for CO_2 capture and liquefaction to super-critical temperatures and pressures. However, it must be stressed that none of these other substances will have been deliberately added to the CO_2 stream for the purposes of waste disposal.

7.5 Long-term monitoring and mitigation of any leakage of CO_2 will be important activities in the context of the London Convention and Protocol, due to the long time-scales of CS-SSGS, the potential for much larger sites than those used for conventional dumping operations and the nature of CO_2.

7.6 There is significant potential for geological storage in structures beneath the oceans. Oil and gas reservoirs and saline formations are expected to have the largest potential to accommodate safe, long-term storage. The aim is to retain CO_2 permanently. Because of the various trapping mechanisms, storage may, in some cases, become more secure over time.

7.7 Because every site is expected to differ in regard to the properties affecting its suitability as a storage site, several important issues should be considered during the site screening and selection process for CS-SSGS, including: the storage capacity and injectivity of the geological formation; the storage integrity; the suitability of the surrounding geological formations; potential migration and leakage pathways over time; and the potential effects on marine life and human health of leakage of CO_2.

7.8 Monitoring techniques for the detection of migration and potential leakage of CO_2 from the intended storage formations are available. The relevant time frames pose challenges with respect to management of the response capacity.

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[7] This option includes CO_2 sequestration in depleted oil and gas fields, but excludes normal oil and gas exploitation operations, such as enhanced oil recovery (EOR).

7.9 Although the intention of the process of CS-SSGS is ‘no leakage’, the need for implementing mitigation measures in response to potential leakages should be based on the likelihood that CO_2 will reach the marine environment and the types and magnitudes of consequent effects.

7.10 The ‘Risk Assessment and Management Framework for CS-SSGS’ can provide useful and important information regarding site-specific risks to the marine environment posed by CS-SSGS, for developing management strategies to address uncertainties and to reduce residual risks to acceptable levels.

7.11 The Guidelines for the Assessment of Wastes or Other Matter that May be Considered for Dumping (the Generic Guidelines adopted in 1997) give guidance for site selection and characterization on a generic level. Specific guidance or a framework for assessment of CS-SSGS would be useful.

Compatibility with Annex 2 of the London Protocol

7.12 The Risk Assessment and Management Framework for CS-SSGS described in this report is compatible with Annex 2 to the London Protocol. It should be noted that this Framework has not addressed, in detail, the waste prevention audit and the waste management options, which are requirements of Annex 2 to the London Protocol. As Contracting Parties are required to address these matters in the assessment of CS-SSGS, further consideration may therefore be necessary.

7.13 Information collected as part of the Problem Formulation (Chapter 1), Exposure Assessment (Chapter 3), and Effects Assessment (Chapter 4) may satisfy the requirements for a chemical, physical and biological characterization of wastes in paragraphs 7 and 8 of Annex 2. The Action list required under Annex 2, paragraphs 9 and 10, may be used by Contracting Parties to identify and prioritize substances in the CO_2 stream during the Problem Formulation and to assess the potential for effects during the Effects Assessment within the Framework. The results of Site Characterization (Chapter 2) and Risk Characterization (Chapter 5) may provide information necessary for dump-site selection (Annex 2: paragraph 11). The conclusions of Exposure Assessment, Effects Assessment, and Risk Characterization may provide input to satisfying the requirements of an assessment of potential effects (Annex 2: paragraphs 12 to 15). Risk Management in the Framework includes the conduct of monitoring as required in Annex 2, paragraph 16. Finally, the Risk Characterization and monitoring conducted as part of Risk Management may provide the process and feedback necessary for reaching permit decisions and reviewing the basis for permits, respectively (Annex 2, paragraphs 17 and 18).

7.14 The Risk Assessment and Management Framework for CS-SSGS is a reasonable starting point for developing specific guidelines for CS-SSGS by the Scientific Group under the London Convention. The development of specific technical guidance related to CS-SSGS would be useful.

APPENDIX 1

INFORMATION FOR SITE SELECTION AND SITE CHARACTERIZATION

The information in this table may facilitate the selection and characterization of sites for CS-SSGS. This table shows possible considerations rather than formal requirements.

ISSUES FOR SELECTION AND CHARACTERIZATION	**DATA AND ANALYSIS TO FACILITATE THE EVALUATION MAY INCLUDE**
Location, geographical and geological factors	**Water depth, structure depth** **Nearness to population centres** **Regional geology, hydrogeology, stratigraphy and structure** **Regional tectonics and seismicity** **Faults and fractures**
Historical uses of the area	**Man-made structures** ✓ active and abandoned wells ✓ well integrity with respect to CO_2
Existence of amenities, biological features and uses of the sea	**Refer to the list in paragraph 6.4 of the Generic Guidelines**
Reservoir/seal evaluation	**Geological interpretation** ✓ stratigraphic interpretations and well-log cross sections of the reservoir intervals ✓ reservoir/seal heterogeneity ✓ temperature, pressure, fluid composition (salinity) **Geophysical mapping** ✓ 3-D maps of potential migration pathways (faults) ✓ structure and thickness of reservoirs and cap rocks **Petrophysics** ✓ permeability, relative permeability (injectivity) ✓ porosity ✓ capillary pressure ✓ mineralogy **Hydrodynamics** ✓ displacement of formation water **Sealing capacity of caprocks** ✓ capillary entry pressure **Geomechanics and geochemistry** ✓ CO_2 – water – rock interaction ✓ stress, stiffness and strength **Reservoir simulations** ✓ short-term behaviour: reservoir response (pressure changes for a given injection rate) ✓ Long-term behaviour: reservoir containment

Marine environment characterization	**Ocean current and see floor topography in the region** **Physical and chemical characteristics of sediments and overlaying waters**: ✓ pH ✓ benthic fluxes of CO_2 ✓ nutrients and other substances (potential contaminants/pollutants) **Biological communities and biological resources** ✓ composition, structure, dynamics **Areas of special scientific or biological importance** ✓ sanctuaries ✓ fishing areas
Economic factors	**Economic feasibility** **Impact on other resources such as oil and gas**

APPENDIX 2

OVERVIEW OF INFORMATION NEEDS FOR RISK MANAGEMENT OF INJECTION SITES FOR CS-SSGS

1 General information needs for risk management include:

- Proximity to other wells (hydrocarbon producers, former or present) or fields, potable, irrigation or industrial water producing wells
- Proximity to other injection wells
- Applicable regulations, codes and standards, and regulatory restrictions and restraints
- History, current status and age of information available on the geological formation

2 Specific information needs for risk management include:

- Sufficient capacity of the reservoir for planned CO_2 storage
- Geology
- Hydrology
- Potential of the injected fluid to cause plugging of the formation
- Compatibility with injected formation chemistry
- Injection and confinement zone hydro-geological and geomechanical properties
- In-situ stress profile in the various layers
- Location, age, depth and condition of water, oil and gas, injection, or other wells, whether active, inactive or abandoned that are likely to be affected by the injection process
- Location, orientation and properties of faults or fractures that are likely to intersect the reservoir
- If an existing well is to be converted for injection, information is needed on well age, its construction details, and its history

APPENDIX 3

GLOSSARY, ACRONYMS AND ABBREVIATIONS

This Appendix contains a glossary, acronyms and abbreviations, which have been selected from a comprehensive glossary in Annex II to IPCC SRCCS. Where appropriate these terms have been adapted for the purposes of this Risk Assessment and Management Framework.

CO_2 capture and sequestration is 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.

Acid gas
Any gas mixture that turns to an acid when dissolved in water (normally refers to H_2S + CO_2 from sour gas (q.v.)).

Anthropogenic source
Source which is man-made as opposed to natural.

Aquifer
Geological structure containing water and with significant permeability to allow flow.

Baseline
The datum against which change is measured.

Blow-out
Refers to catastrophic failure of a well when the petroleum fluids or water flow unrestricted to the surface.

Brine
Water with a high concentration of dissolved salts.

Buoyancy
Tendency of a fluid or solid to rise through a fluid of higher density.

Capillary entry pressure
Additional pressure needed for a liquid or gas to enter a pore and overcome surface tension.

Cap rock
Rock of very low permeability that acts as an upper seal to prevent fluid flow out of a reservoir.

Casing
A pipe which is inserted to stabilize the borehole of a well after it is drilled.

D, Darcy
A non-SI unit of permeability, abbreviated D, and approximately = $1\mu m^2$.

Dense phase
A gas compressed to a density approaching that of the liquid.

Dense fluid
A gas compressed to a density approaching that of the liquid.

Dissolution
With respect to CO_2, the process by which CO_2 separates into its component ions in water.

Completion of a well
Refers to the cementing and perforating of casing and stimulation to connect a well bore to reservoir.

Containment
Restriction of movement of a fluid to a designated volume (e.g. reservoir).

Deep saline aquifer
A deep underground rock formation composed of permeable materials and containing highly saline fluids.

Depleted
Of a reservoir: one where production is significantly reduced.

EOR
Enhanced oil recovery: the recovery of oil additional to that produced by standard production methods.

Fault
In geology, a surface at which strata are no longer continuous, but displaced.

Flood
The injection of a fluid into an underground reservoir.

Formation
A body of rock of considerable extent with distinctive characteristics that allow geologists to map, describe, and name it.

Formation water
Water that occurs naturally within the pores of rock formations.

Fracture
Any break in rock along which no significant movement has occurred, but where the permeability may be significantly enhanced.

Geochemical trapping
The retention of injected CO_2 by geochemical reactions.

Geological time
The time over which geological processes take place.

Geomechanics
The process of movement or potential movement of rocks within the Earth's crust.

Geosphere
The earth, its rocks and minerals, and its ground waters.

GHG
Greenhouse gases: carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), hydroflurocarbons (HFCs), perfluorocarbons (PFCs), and sulphur hexafluoride (SF_6).

Hydro-geological
Concerning water in the geological environment.

Hydrostatic
Pertaining to the properties of a stationary body of water.

IEA GHG
International Energy Agency – Greenhouse Gas R&D Programme.

Igneous
Rock formed when molten rock (magma) has cooled and solidified (crystallized).

Injection well
A well in which fluids are injected rather than produced.

Injectivity
A measure of the rate at which a quantity of fluid can be injected into a geological formation.

In-situ mineralization
A process whereby carbon dioxide injected into a geological formation reacts with silicate minerals, forming stable carbonate minerals.

IPCC
Intergovernmental Panel on Climate Change.

Leakage
In respect of carbon storage, the escape of CO_2 from the storage formation into the water column and the atmosphere.

Log
Records taken during or after the drilling of a well.

Mature sedimentary basins
Geological basins formed by the deposition of sedimentary particles and grains under sub-aqueous and sub-aerial conditions and in which deposited organic matter has matured into hydrocarbon reserves.

Microseismicity
Small-scale seismic activity, usually only detectable by the use of sensitive instrumentation.

Migration
The movement of fluids within or out of reservoir rocks.

Mitigation
The process of reducing the impact of any failure in the CO_2 storage system.

Monitoring
The process of measuring the quantity of carbon dioxide stored, its location and its behaviour.

Monte Carlo simulation
A modelling technique in which the statistical properties of outcomes are tested by random inputs.

Mudstone
A very fine-grained sedimentary rock that commonly provides a seal, thus preventing the upward migration of fluids.

Observation well
A well installed to permit the direct observation of subsurface conditions.

Overburden
Rocks and sediments above any particular stratum.

Overpressure
Pressure created in a reservoir that exceeds the pressure inherent at the reservoir's depth.

OSPAR
Convention for the Protection of the Marine Environment of the North-East Atlantic, which was adopted at Paris on 22 September 1992.

Permeability
Ability to flow or transmit fluids through a porous solid such as rock.

Pore space
Space between sedimentary grains that can contain fluids.

Porosity
Measure of the amount of pore space in a rock.

Regional scale
A geological feature that crosses an entire basin, or other geological provinces.

Remediation
The process of correcting any source of failure, for example in a CO_2 storage system.

Reservoir
A subsurface body of rock with sufficient porosity and permeability to store and transmit fluids.

Risk assessment
Part of a risk-management system.

Saline formation
Sediment or other rock formation containing brackish water or brine.

Seal
An impermeable rock that forms a barrier above or around a reservoir such that fluids are held in the reservoir.

Seismic technique
Measurement of the properties of rocks by the speed of sound waves generated artificially or naturally.

Shale
An impermeable very fine-grained and finely laminated sediment that commonly provides a seal to the movement of underlying fluids.

Sour gas
Natural gas containing significant quantities of acid gases like H_2S and CO_2.

Spill point
The structurally lowest point in a structural trap (q.v.) that can retain fluids lighter than background fluids.

Storage
A process for retaining captured CO_2 in deep geological formations so that it does not reach the atmosphere.

Structure
Geological feature produced by the deformation of the Earth's crust, such as a fold or a fault; a feature within a rock such as a fracture; or, more generally, the spatial arrangement of rocks.

Supercritical
At a temperature and pressure above the critical temperature and pressure of the substance concerned. The critical point represents the highest temperature and pressure at which the substance can exist as a vapour and liquid in equilibrium.

Tectonically active area
Area of the Earth where deformation is presently causing structural changes.

Trap
A geological structure that physically retains fluids that are lighter than the background fluids.

Well
Manmade hole drilled into the earth to produce liquids or gases, to allow the injection of fluids, or to enable observations of subsurface process.

Wellhead pressure
Pressure developed at the top of the well.

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[i] The Generic Guidelines for the Assessment of Wastes and Other Matter that May be considered for Dumping were adopted in 1997 (LC 19/10, annex 2).

[ii] Draft Discussion paper from the Task Force for Reviewing and Identifying Standards with Regards to CO_2 Storage Capacity Measurement, CSLF 2005.

[iii] IPCC SRCCS: p. 141.

[iv] IPCC SRCCS: pp 244-246.

[v] IPCC SRCCS: pp 244-246 and 250-251.

[vi] IPCC SRCCS: pp 242-251, Table 5.5.

[vii] IPCC SRCCS: p. 197; p. 249.

[viii] According to the IPCC SRCCS, there are two types of leakages, i) abrupt leakages and ii) gradual leakages.

[ix] Poremski, 2004, in LC/SG-CO2 1/INF.2.

[x] OSPAR 2006. Effects on the Marine Environment of Ocean Acidification Resulting from Elevated Levels of CO_2 in the Atmosphere.

[xi] See IPCC SRCCS, Chapter 6, for an overview of existing data.

[xii] OSPAR 2006. Effects on the Marine Environment of Ocean Acidification Resulting from Elevated Levels of CO_2 in the Atmosphere.

[xiii] IPCC SRCCS, p. 311.

[xiv] OGP 2000. Guidelines for Produced Water Injection. Report 2.80/302, January 2000, International Association of Oil and Gas Producers.

[xv] OSPAR. 2001. Environmental Aspects of On and Off-Site Injection of Drill Cuttings and Produced Water. Oslo Paris Commission ISBN 0 946956 69 3.

[xvi] IPCC 2006. DRAFT Guidelines for National Gas Inventories. Intergovernmental Panel on Climate Change.