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LC.2/Circ.439
31 March 2005

**CONVENTION ON THE PREVENTION OF MARINE POLLUTION BY DUMPING OF
WASTES AND OTHER MATTER, 1972
(LONDON CONVENTION 1972)**

**Invitation to consider the legal questions associated with CO₂ sequestration in geological
formations under the London Convention and Protocol**

1 In November 2004, the 26th Consultative Meeting of Contracting Parties considered the challenge of stabilizing greenhouse gas concentrations in the atmosphere and recognized that CO₂ capture and storage in geological structures might offer important possibilities for making fossil fuel use more compatible with climate change mitigation policies. In this context, the Meeting agreed that the issue of CO₂ sequestration should be included in its work programme and to initially focus on sequestration of CO₂ in geological structures. Several activities were planned for the intersessional period to examine the legal, scientific and technical issues involved so that the next Meeting could review the progress and give guidance on what further work should be done to establish a clear position. (See also LC.2/Circ.438 in this regard.)

2 The 26th Consultative Meeting *inter alia* established a correspondence group under the lead of the United Kingdom to consider the legal issues associated with CO₂ sequestration in geological structures under the London Convention and Protocol. The United Kingdom recently completed a final list of legal questions, which is attached hereto in annex 1, while a “Factual Description and Glossary for CO₂ Discussions under the London Convention and Protocol” is attached in annex 2. This factual description was also submitted to the 28th session of the Scientific Group (LC/SG 28/3/Rev.1), as a basis for its work in May 2005.

3 The final version of the legal questionnaire has been expanded to incorporate additional elements recommended. The United Kingdom has tried to be inclusive of all suggestions it received when a draft was circulated in December 2004 and to phrase the questions neutrally so as not to prejudice the debate on the answers. Where some suggested detail has not been incorporated, this is because the material proposed was more in the nature of answers to the questions than an elaboration of the questions. All material submitted has been retained on file, and will be reflected in the composite paper to be submitted to the Consultative Meeting. The United Kingdom wishes to emphasize that the purpose of the questionnaire is to stimulate and help structure debate on the legal issues; it is not intended to limit debate nor to preclude any delegation from submitting additional comments.

4 The recipients of this questionnaire are kindly invited to prepare their views on these legal questions and send these directly and as soon as possible **but not later than Friday, 17 June 2005** to the co-ordinator for this activity, Ms. Gail Clarke in the United Kingdom (gail.clarke@defra.gsi.gov.uk, Tel: +44-20-7270-8655). All respondents should state clearly which organization they represent to ensure that views expressed are accurately accredited.

5 The United Kingdom Government will analyse the responses received and prepare a consolidated paper on the legal issues for submission by Friday, 22 July 2005 to the 27th Consultative Meeting (24 to 28 October 2005). Where views converge, this will be reported but, on issues where views diverge, the alternative views will be set out as a basis for further debate at that Meeting. The Consultative Meeting will then review the progress and give guidance on what further work should be done to establish a consensus.

6 This invitation was also sent by email on 23 March 2005 to those national focal points which have advised IMO of their e-mail contact addresses as well as to Heads of delegations of both Contracting Parties and observer organizations that attended the 26th Consultative Meeting.

ANNEX 1

**SEQUESTRATION OF CO₂ IN SUB-SEABED GEOLOGICAL STRUCTURES:
COMPATIBILITY WITH THE LONDON CONVENTION/PROTOCOL:
LEGAL ISSUES****A: OUTLINE OF THE POSSIBLE FACTUAL SCENARIOS**

For detail, please see the “Factual Description and Glossary for CO₂ discussions under the London Convention and Protocol” provided in a separate document, and which is also circulated to the Scientific Group under LC/SG 28/3/Rev.1.

In summary, the most likely factual scenarios are assumed to be the following seven. In accordance with the terms of reference of this consultation, the scenarios under consideration are limited to sub-seabed geological storage and do not involve storage of CO₂ in the water column.

Scenario 1 (The reference case)

CO₂ is generated on land, transported via a pipeline to an offshore structure, and injected into a sub-seabed geological storage facility.

Scenario 2

CO₂ is generated on land, transported via a pipeline and injected into a sub-seabed geological storage facility.

Scenario 3

CO₂ is generated on land, transported via a ship to an offshore structure and injected into a sub-seabed geological storage facility.

Scenario 4

CO₂ is generated on land, transported via a ship and injected from that ship (or other floating structure) into a sub-seabed geological storage facility.

Scenario 5

CO₂ is generated offshore (e.g. by separation from natural gas extraction) and injected from that offshore structure into a sub-seabed geological storage facility.

Scenario 6

CO₂ is generated offshore (e.g. by separation from natural gas extraction), transported by ship to another offshore structure and injected into a sub-seabed geological storage facility.

Scenario 7

CO₂ is generated offshore (e.g. by separation from natural gas extraction), transported by pipeline to another offshore structure and injected into a sub-seabed geological storage facility.

B: LEGAL QUESTIONS

It is suggested that in considering your answers to the following questions, the facts outlined in Scenario 1 above (The reference case) be assumed, as, on current information, this scenario is likely to be the most common. You are then invited to consider whether your answers might be different if the facts were as outlined in Scenarios 2 - 7, and if so, to indicate how.

In considering questions of treaty interpretation, it is assumed that reference will be made to the Vienna Convention on the Law of Treaties 1969, in particular Articles 31 – 33 on interpretation of treaties.

(i) London Convention 1972

Question 1. Does sequestration of CO₂ fall within the definition of “dumping” in Article III.1(a)(i)?

- (a) Is sequestration of CO₂ “deliberate disposal”? In particular, if the intention is to retrieve it in the future, is it “deliberate disposal”?
- (b) Does “sea” include the seabed and the sub-soil thereof? Does “sea” include sub-seabed reservoirs/storage facilities? (See definition of “sea” in Article III.3)
- (c) What does “*at sea*” mean?
- (d) Is CO₂ “wastes or other matter”? (See definition of “wastes or other matter” in Article III.4)
- (e) Is it envisaged that sequestration might involve disposal otherwise than “from vessels, aircraft, platforms or other man-made structures at sea”? In particular, what are “other man-made structures at sea”? Does this term include pipelines lying on the seabed?

If the answer to Q1 is yes, we need to consider:

Question 2. Does sequestration of CO₂ fall within any of the exclusions from the definition of “dumping” in Article III.1?

- (a) Is the CO₂ incidental to or derived from “the normal operations of vessels, aircraft, platforms or other man-made structures at sea and their equipment”? (See the exclusion in Article III.1(b)(i))
- (b) Is it “placement of matter for a purpose other than the mere disposal thereof”? (See the exclusion in Article III.1(b)(ii))
- (c) What does “provided it is not contrary to the aims of this Convention” mean? (See Article III.1(b)(ii) and question 7 below)
- (d) Is it excluded under Article III.1(c) as related to exploration, exploitation or associated offshore processing of seabed mineral resources?

If the answer to Q2 is no, we need to consider:

Question 3. Is sequestration of CO₂ prohibited under Article IV.1(a) and Annex I?

- (a) In particular, is CO₂ “industrial waste” under paragraph 11 of Annex I?

- (b) How likely is it that contaminants listed in paragraphs 1-5 of Annex I would be present in the CO₂ at higher than trace levels? If so, does this bring it within paragraph 11 and therefore within the prohibition in Article IV(1)(a)?

OR

Question 4. Does sequestration of CO₂ require a special permit under Article IV.1(b) and Annex II?

OR

Question 5. Does sequestration of CO₂ require a prior general permit under Article IV.1(c) and Annex III?

Question 6. Is sequestration of CO₂ “pollution” as referred to in Articles I and II?

Question 7. Do Articles I and II assist in the interpretation and application of Articles III and IV to the above questions?

- (a) What does “all sources of pollution of the marine environment” in Article 1 mean? How wide is this expression? Does it, for example, include pollution by CO₂ from the atmosphere?
- (b) How do Articles 1 and 2 affect the interpretation of the expression “the aims of this Convention” in Article III.1(b)(ii)?

(ii) 1996 Protocol to the London Convention 1972

Question 1. Does sequestration of CO₂ fall within the definition of “dumping” in Article 1.4.1?

- (a) Is sequestration of CO₂ “deliberate disposal” under Article 1.4.1.1? Even if future retrieval is intended?
- (b) What does “into the sea” mean? (See definition of “sea” in Article 1.7 and Question 4 below.)
- (c) Is CO₂ “wastes or other matter”?
- (d) Is sequestration of CO₂ “storage” under Article 1.4.1.3?
- (e) What does “in the seabed and the subsoil thereof” mean? (See definition of “sea” in Article 1.7 and Question 4 below.)
- (f) Is it envisaged that sequestration of CO₂ might involve “deliberate disposal” or “storage” otherwise than “from vessels, aircraft, platforms or other man-made structures at sea”? (relevant to Article 1.4.1.2 and .3)

If the answer to Q 1 is yes, we need to consider:

Question 2. Does sequestration of CO₂ fall within any of the exclusions from the meaning of “dumping” in Article 1.4.2?

- (a) Could it come under the “normal operations” exclusion in Article 1.4.2.1? (is it “incidental to, or derived from the normal operations of vessels, aircraft, platforms or other man-made structures at sea and their equipment”?)
- (b) Could it be “placement for a purpose other than the mere disposal” under Article 1.4.2.2?
- (c) What does “provided that such placement is not contrary to the aims of this Protocol” mean?

Question 3. Is sequestration of CO₂ excluded from the scope of the Protocol by Article 1.4.3? (as arising from, or related to, the exploration, exploitation, and associated offshore processing of seabed mineral resources)?

Question 4. Does the definition of “sea” in Article 1.7 include sub-seabed geological formations, such as depleted oil reservoirs or gas fields, deep saline aquifers or unmineable coal seams?

- (a) What is meant by “the seabed and the subsoil thereof” in Article 1.7? Does it include areas below the sub-soil? How far down does the “sub-soil” go? Was the Protocol intended to apply to geological structures thousands of metres below the seabed or to the immediate sub-soil (hundreds of metres)?
- (b) What is the significance of the express exclusion of “sub-seabed repositories accessed only from land”?
- (c) Do the provisions of or practice under the UN Convention on the Law of the Sea provide any useful guidance?
- (d) How does the answer to this question affect the answer to Q1 above?

Question 5. Does Article 2 (Objectives) assist the interpretation and application of Article 1 to these questions?

- (a) What does “all sources of pollution” mean? How wide is this expression? Does it, for example, include pollution by CO₂ from the atmosphere?
- (b) How does this Article affect the interpretation of the expression “the aims of this Protocol” in Article 1?

Question 6. Is sequestration of CO₂ “pollution” within the meaning of Article 1.10?

- (a) How does the answer to this question affect the interpretation of Article 2?

- (b) Does this assist the interpretation and application of Article 1?

Question 7. Does Article 3 (General Obligations) assist the interpretation and application of Article 1 to these questions?

- (a) What is the effect, if any, of the obligation in Article 3.1 to apply “a precautionary approach to environmental protection”?
- (b) What is the effect, if any, of the obligation in Article 3.2 to take into account the approach that the polluter should, in principle, bear the cost of pollution?
- (c) What is the effect, if any, of the obligation in Article 3.3 to act so as not to transfer damage or transform one type of pollution into another?

Question 8. Is CO₂ within the definition of any of the items on Annex 1, which are excluded from the prohibition on dumping in Article 4.1.1?

- (a) Is it “inert, inorganic geological material” within the meaning of paragraph 1.5 of Annex 1?
- (b) Is it “organic material of natural origin” within the meaning of paragraph 1.6 of Annex 1?

If the answer to Q8 is yes, we need to consider:

Question 9. Could sequestration of CO₂ be authorized under Article 4.1.2 and Annex 2?

- (a) What would be the main considerations relevant to assessment under Annex 2?
- (b) How should it be regulated?
- (c) What is the impact of the last sentence of Article 4.1.2 (“Particular attention shall be paid to opportunities to avoid dumping in favour of environmentally preferable alternatives.”)?

Question 10. What is the relevance, if any, of Article 6 regarding the export of wastes or other matter?

(iii) Other legal factors

What is the relevance of other international legal instruments and work in progress in other legal fora on this subject? (See the separate note by the Secretariat concerning the developments in the OSPAR framework (LC/SG 28/INF.6.)

Are there any relevant principles of customary international law that should be taken into account?

Finally, the above questions are not intended to limit debate; if you wish to add any additional comment or raise any additional legal issues, please feel free to do so.

ANNEX 2

CARBON DIOXIDE SEQUESTRATION USING GEOLOGICAL STRUCTURES

A FACTUAL DESCRIPTION AND GLOSSARY FOR CO₂ DISCUSSIONS UNDER THE LONDON CONVENTION AND PROTOCOL

INTRODUCTION

1 Anthropogenic emissions of greenhouse gases are causing global warming with sea level rise, and acidification of the sea. The major contributor is carbon dioxide (CO₂), which arises mainly from use of fossil fuels. Measures, such as improved energy efficiency and use of alternative energy sources, will help reduce emissions. However, considering that approximately 85% of the world's commercial energy needs are met by fossil fuels, a rapid move away from fossil fuels is unlikely to be achievable without serious disruption to the global economy. It has now been recognized that emissions of CO₂ from fossil fuel utilization could be significantly reduced by its capture and geological storage. Capture and storage of CO₂ may therefore provide the means to rapidly achieve large reductions in greenhouse gas emissions.

2 The overall concept is to capture CO₂ from combustion of fossil fuels and store it for thousands of years in natural underground reservoirs. The technology for capturing CO₂ from power plant and other major sources is already largely available. CO₂ capture and storage technology could also be used to produce hydrogen without emissions, thereby facilitating introduction of hydrogen as an energy carrier. Storage of CO₂ is technically feasible in natural geological structures which have sufficient capacity for many years' emissions. Many of these potential storage reservoirs are beneath the sea-bed.

CARBON DIOXIDE CAPTURE

3 CO₂ capture is best applied to large stationary sources, which offer economies of scale in construction and minimize the extent of the supporting transport network. Therefore, most current work has focused on its application to power generation and other large process plant such as oil refineries and coal gasification plant, and looking to the longer term, hydrogen production facilities.

4 There are three generic processes routes for capturing CO₂ from fossil fuel power plant:

- post-combustion capture – this is most applicable to existing and new pulverized fuel power stations;
- pre-combustion capture – this is most applicable to new integrated gasification combined cycle (IGCC) power plant; and
- oxyfuel combustion – this is most applicable to new pulverized fuel power stations.

CARBON DIOXIDE TRANSPORT

5 CO₂ can be stored and transported in gaseous, liquid or solid forms. However, because the CO₂ captured from flue gases is in gaseous form, and large capital investments would be needed to construct the cryogenic plant needed for liquefaction or solidification, transportation is also likely to be undertaken in the gas phase (strictly speaking the supercritical dense phase). Furthermore,

liquefaction or solidification would require appreciable energy input, which would impact on the overall energy balance of the process and thereby reduce its net abatement of CO₂.

6 Bulk gaseous transport of CO₂ may be undertaken by tanker (road, rail or water) or by pipeline, but with the large volumes involved in a sequestration scheme (10-30Mt CO₂ per year), pipeline transport is most likely practical option. Practical experience in the United States has shown that CO₂ transport by pipeline is an established commercial technology. Tanker transport may have a role in smaller demonstration projects of the order of 100-200kt CO₂ per year.

CARBON DIOXIDE GEOLOGICAL PLACEMENT AND STORAGE

7 Various methods have been proposed for storage or management of captured CO₂ including placement into geological formations, deposition into the water column on the deep ocean floor and conversion into solid minerals. The current work focuses on placement into geological formations, this is because this represents the most secure and least risk option, and the understanding of the processes is more advanced. Geological storage of CO₂ requires permeable rock strata that provide space for the gas to be stored.

Geological Storage Mechanisms

8 The security of CO₂ placement and storage in geological structures depends on a combination of physical and geochemical mechanisms. The most effective sites are those where the CO₂ is physically trapped permanently beneath a low permeability caprock, which acts as a seal. Sedimentary basins have many such closed structures, containing oil, gas or saline water. Another form of physical trapping is hydrodynamic trapping, where the saline formation water migrates at a very slow rate. Injected CO₂, whilst initially buoyant and rising to the top of the structure, dissolves over time and migrates with the saline water. For large formations, this migration can take millions of years before reaching the surface. CO₂ may also undergo a series of geochemical reactions which further increase storage security and capacity. Firstly, when CO₂ dissolves in formation water, solubility trapping occurs as it loses its buoyancy and sinks. Next, ionic trapping occurs as the host rock dissolves accompanied by a rise in pH. Finally, mineral trapping may occur, where some CO₂ may slowly convert to stable carbonate mineral phases, which are the most permanent form of CO₂ storage. Another type of storage mechanism occurs in coal and organic-rich shales, where CO₂ is preferentially adsorbed onto the surfaces within the cracks and micropores.

Geological Structure Options

9 There are three main options for suitable geological structures:

- depleted or near depleted oil and gas reservoirs;
- deep saline aquifers; and
- unmineable coal seams.

10 **Oil reservoirs** can be used for placement and storage of CO₂ and are a good option since their geological structures have retained hydrocarbons over very long geological timescales. Also they will have been extensively investigated and mapped during production thus providing essential knowledge for selecting suitable reservoirs and managing their utilization. The capacity of an oil reservoir to store CO₂ is made up of the pore space vacated by the oil together with additional pore space occupied by "bottom waters" lying below the oil formation.

11 **Enhanced oil recovery (EOR)** can use CO₂ to mobilize some of the oil remaining in a reservoir after primary and secondary production is complete. It does this by dissolving in the oil thereby reducing the oil's effective viscosity and making it more mobile. The movement of the CO₂ front within the reservoir can then sweep the oil to the production wells. CO₂ based EOR is an established onshore procedure in North America but has not yet been undertaken offshore, although up to 15Mt per year of nitrogen is injected into the Cantarell oil field lying 60 miles off the Mexican coast. An EOR operation would store CO₂ in the pore space of the oil-containing rock. To utilize the storage space associated with underlying water it would be necessary to develop a new strategy, possibly with additional injection wells, after oil production is finished. About 33mt pa of CO₂ is already used at over 70 EOR projects in the United States. The Weyburn project is a good example, as the CO₂ is captured from a coal gasification plant in the United States and piped to an oil field in Canada. This project is being closely monitored by an international research project.

12 **Gas fields**, like oil reservoirs, exist because they have seals that prevented migration over long periods of time. Placement and short-term storage of natural gas in natural underground reservoirs has been common practice in industry for many years, and gas is routinely injected into, stored and withdrawn from hundreds of underground storage fields. Although CO₂ injection could help with some additional gas extraction from a field, the benefits are less than for EOR and storage would generally be considered when the field was largely depleted. A key factor is the operational record of the field. For example if the pore space has been filled by the ingress of water more energy will be needed to inject the CO₂ in order to overcome capillary forces. Operating records should be available to check on these factors when selecting candidate fields. An example which commenced in 2004 is the In Salah Gas project in Algeria, where CO₂ will be separated from the extracted natural gas and re-injected into the gas reservoir.

13 **Deep saline aquifers** present the largest potential capacity for storage of all the geological options. They could be used because they have little if any foreseeable value as a source of water for drinking or irrigation because of their depth and high dissolved mineral content. Two basic types occur – open and closed. Closed aquifers have defined boundaries produced by geological folding or faulting which considerably reduces the possibility for lateral movement of CO₂ into potable aquifers or to the surface. This makes them the preferred option for CO₂ storage, but their capacity is less than for open aquifers. Open aquifers are extensive flat or gently sloping formations of water bearing rock. Because they are open CO₂ can move laterally, but the slow rate of transport, combined with their size means that the gas will be confined for many centuries. Immobilization of the CO₂ in both types of aquifer may come from its dissolution in the water in the aquifer, which will reduce buoyancy and sink, and by reaction with minerals to form solid compounds.

14 The world's first commercial scale storage of CO₂ in aquifers was begun by Statoil in 1996 in conjunction with natural gas production from the Sleipner Field in the North Sea. Up to 1Mt CO₂/yr has so far been injected into an aquifer formation about 800m below the seabed. Much research is underway to monitor the containment and behaviour of the CO₂.

15 Another example is the Gorgon project in Australia which plans to separate CO₂ from extracted natural gas, and inject from an island into a saline aquifer which extends under the sea.

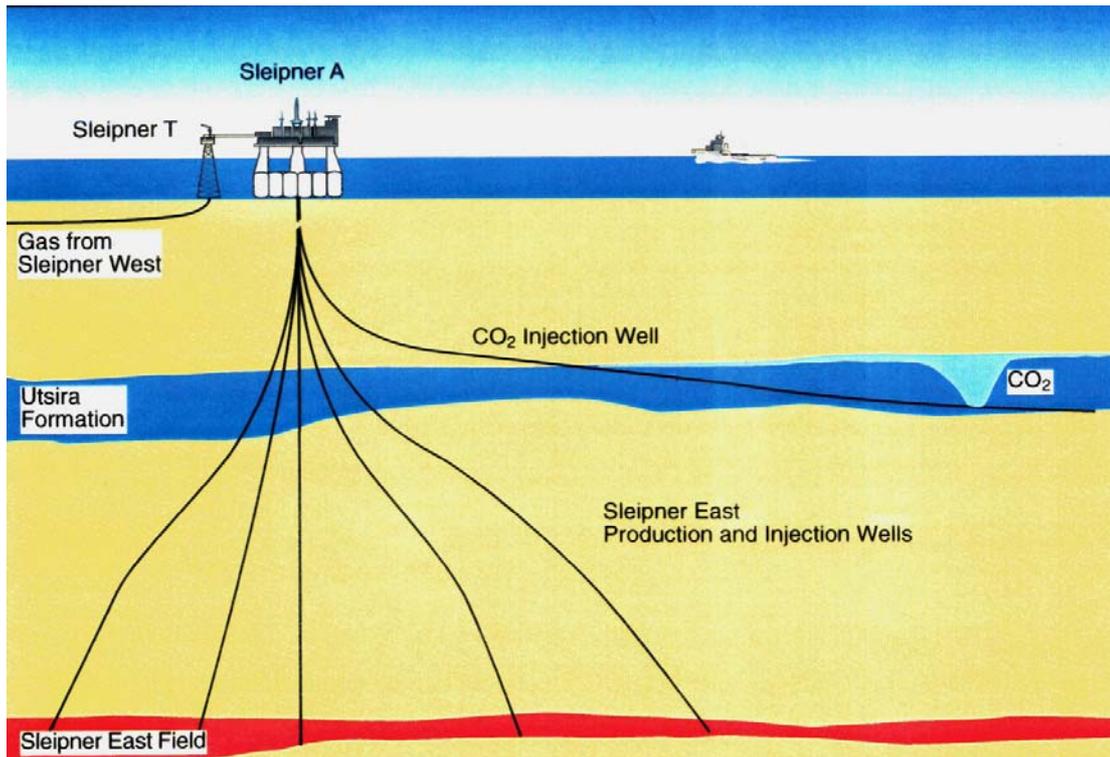


Figure 1. CO₂ separation and injection at Sleipner (Courtesy Statoil). Note that the schematic is not to scale – the sea is approximately 80m deep and the Utsira aquifer is approximately 800m beneath the sea bed.

16 **Coal seams** offer a storage option because the CO₂ is preferentially adsorbed by the coal, displacing previously adsorbed methane. This does render the coal no-longer suitable for mining, as this may release the CO₂. In addition to offering storage for CO₂ there is potential to collect the desorbed methane thus gaining a financial return. A key factor in this form of storage is the permeability of the coal seam. This storage option is currently at the research stage.

Capacity for Storage

17 Global geological storage capacities have been estimated by the IEA Greenhouse Gas R&D Programme. These are:

Depleted oil fields	125Gt of CO ₂
Depleted gas fields	800Gt of CO ₂
Deep saline aquifers	400 to 10,000Gt of CO ₂
Unmineable coal seams	148Gt of CO ₂ .

18 With current world CO₂ emissions of about 25Gt per year (6GtC/year) it is clear that CO₂ capture and storage has potential global significance for greenhouse gas abatement.

Verification

19 If CO₂ sequestration were to be used as a basis for emissions trading or to meet national commitments under the UNFCCC, it would be necessary to monitor the CO₂ stored in a verifiable manner.

20 For CO₂ capture, the flows of gas would be measured as a normal part of the chemical engineering of the process; technology already exists to do this and additional costs would be small. It has already been shown, from experience of SO₂ trading in the United States, that capture of flue gases can be measured with great accuracy and at low cost. Also, with transport of CO₂, pipelines already carry CO₂ across the United States on a commercial scale, with large quantities of CO₂ monitored accurately in real time using equipment that is available now at low cost.

21 Similar measurements would be used to monitor CO₂ placed into geological reservoirs. The necessary equipment is already built into most oil and gas facilities, enabling verification at minimal cost. Movement of gases underground can be measured by seismic monitoring, and this is being demonstrated at Sleipner. At Sleipner, it is considered that the detection resolution is approximately 2800t CO₂ at the 800m depth beneath the seabed, and 600t CO₂ if the CO₂ were to seep up to 400m depth (1mt CO₂ are being injected each year). It is important to stress that the detection resolution would be site specific. In some cases the CO₂ would be in the liquid/supercritical state, with densities much closer to those of water and oil, so different techniques would be used to monitor movement underground. Overall, monitoring of CO₂ underground would aim to verify location and movement against that predicted by detailed modelling of the geological behaviour, and alert if CO₂ behaviour was different to that predicted. For more information visit the following websites: <http://www.ieagreen.org.uk>; <http://www.dti.gov.uk/energy/coal/offt>; <http://www.cslforum.org>.

22 Over time, reaction with reservoir rock may be more difficult to follow using remote sensing techniques. Nevertheless, most verification requirements for geologically placed CO₂ can be achieved with technology available today.

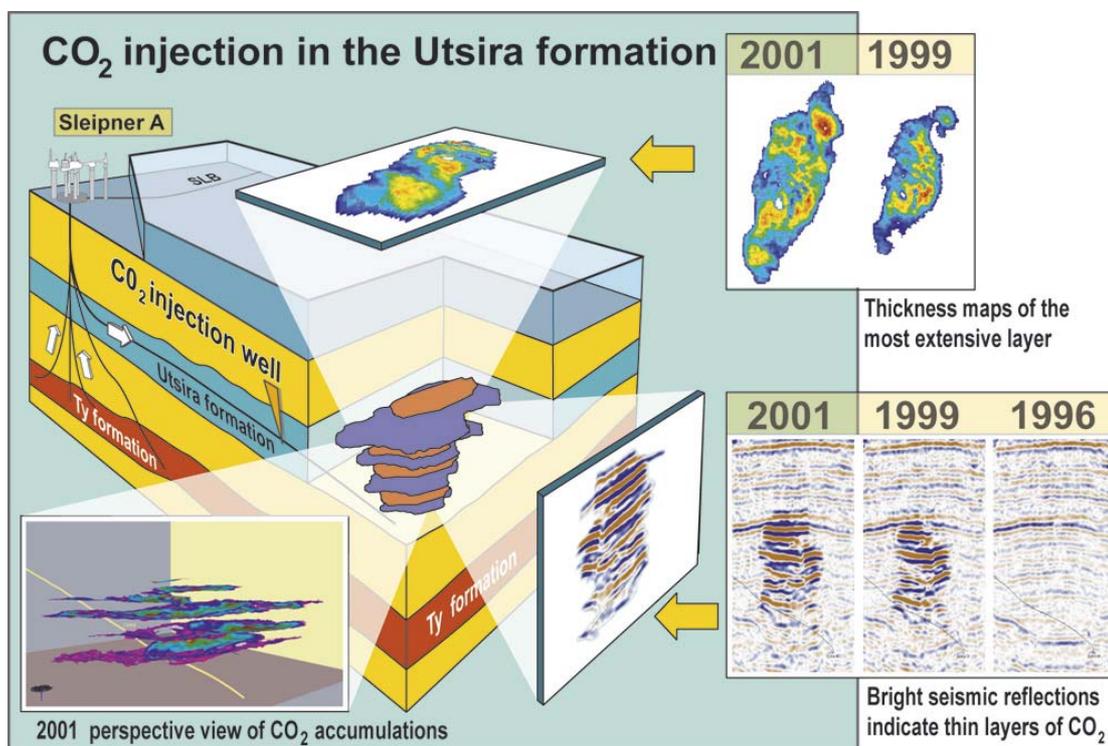


Figure 2. Sleipner schematic showing seismic images of stored CO₂ (Courtesy Statoil). Note that the schematic is not to scale – the sea is approximately 80m deep and the Utsira aquifer is approximately 800m beneath the sea bed.

GLOSSARY

For the purposes of assisting clarification and understanding only, not necessarily rigid definitions.

Avoided GHG Emissions: A measurement of greenhouse gas (GHG) emissions reduction that takes into account the reduced capacity of power plants and other industrial facilities due to the addition of CO₂ capture systems. For example, if a capture system were installed at a power plant that emitted 100 units of CO₂ per year, and the capture system captured 90% of the CO₂ but reduced the power plant's output from 50 units/yr to 40 units/yr, the reduction in terms of avoided emissions would be 10/40 versus 100/50 - a reduction of 87.5%, which is less than 90%. Often avoided-emissions calculations assume a method of making up lost capacity. In the above example, if the lost capacity was made up with a power plant without CO₂ controls (100/50), then the new emissions would be 30 units CO₂ per year (10 + (10/50)*100), which gives an avoided emissions rate of 70 units CO₂ per year - again less than the 90 units of CO₂ per year that are captured.

Carbon Dioxide (CO₂): A colourless, odourless gas that is produced when animals (including humans) breathe or when carbon-containing materials (including fossil fuels) are burned. Carbon dioxide is essential to the photosynthesis process that sustains plant and animal life, however, it can accumulate in the air and trap heat near the Earth's surface (the "greenhouse effect").

CO₂ Capture: The removal of CO₂ from a process stream or from the atmosphere to produce a highly pure stream of CO₂ amenable for conversion or storage. CO₂ capture systems are assessed on the purity of the captured CO₂, the percent of total CO₂ that is captured, and the capital cost and energy use per unit of CO₂ captured.

Enhanced oil recovery (EOR): Increased production of oil from an oil field by injecting gas (e.g. CO₂) and/or water to mobilize and move oil out for the field. In the most common CO₂ enhanced oil recovery (EOR) method, miscible CO₂ EOR, CO₂ becomes dissolved in the crude oil and both causes the oil to swell and reduces its viscosity - which drives and enables the oil to slip through the rock formation toward the oil recovery well. In 2000, CO₂ EOR accounted for 5% of total United States oil production. It is estimated that 3,000 to 8,000 standard cubic feet of CO₂ remains sequestered in a formation for every barrel of enhanced oil recovered.

Fossil Fuel: Any naturally occurring fuel of an organic nature formed by the decomposition of plants or animals; includes coal, natural gas, and petroleum.

Geological Formation: A contiguous underground material which is sufficiently homogeneous to be considered a single unit. Geological formations with a certain structure and porosity present an opportunity for underground CO₂ placement, as evidenced by existing formations which have been storing CO₂ for millions of years. Examples of formations with CO₂ sequestration potential include depleted oil reservoirs, depleted gas reservoirs, unmineable coal seams, saline formations, and shale formations.

Global Warming Potential (GWP): A measure of the magnitude of the heat-trapping effect resulting from the addition of 1 kilogram of a gas to the atmosphere relative to that of 1 kilogram of carbon dioxide. GWP is a function of two factors: (1) the instantaneous heat-absorbing ability of the gas, and (2) the length of time that emissions of the gas persist in the atmosphere, on average. Gases differ substantially in both heat-trapping ability and atmospheric lifetime. For example, methane is

over 100 times more capable of heat trapping than CO₂, but methane's average atmospheric lifetime is only 12 years, compared to CO₂ which persists anywhere between 5 and 200 years. Most GWPs are reported as the average heat trapping effect over 100 years. The 100-year GWP for methane is 23; the 100-year GWP for CO₂, by definition, equals 1.

Greenhouse Effect: The warming of the Earth's surface and lower atmosphere caused by the trapping of radiated heat, much the same way the coated window panes of an agricultural greenhouse keep heat inside the greenhouse. Several gases, such as carbon dioxide and methane, can keep heat from escaping from the Earth into space and are called "greenhouse gases."

Greenhouse Gas (GHG): A gas which does not absorb radiation of wavelengths in the visible light spectrum, but does absorb infrared (heat) radiation. In the atmosphere these gases allow energy from the sun to reach the earth's surface, but limit infrared energy (heat) from escaping. This effect is called radiative forcing. Greenhouse gases absorb 90% of infrared energy radiating from the Earth. Water vapour is the primary GHG, and CO₂ is the most important GHG emitted to the atmosphere as a result of human activities. CO₂ accounts for over 80% of the anthropogenic GHG effect. Other GHGs include: methane (CH₄), ozone (O₃), CFCs (CFC-11, CFC-12, CFC-113), HFCs (HCFC-22) and nitrous oxide (N₂O), CCl₄, methyl chloroform, sulfur hexafluoride, trifluoromethyl sulfur pentafluoride, and perfluoroethane. Each gas has a different global warming potential and longevity in the atmosphere.

Hydrates: A hydrate is a naturally occurring, ice-like crystalline compound in which a crystal lattice of water molecules encloses a molecule of some other substance. The compounds are very dense and insoluble in water. CO₂ hydrates are being investigated for use in CO₂ capture and storage.

Membrane: A material that is selectively permeable to one or more chemical species and can therefore be used to separate that species from a gas stream. Selective separation is driven by the partial pressure difference across the membrane surface. Membrane materials are being developed for the separation of CO₂ from hydrogen, natural gas, and flue gas.

Measurement, Monitoring, and Verification (MM&V): MM&V is defined as the capability to measure the amount of CO₂ stored at a specific sequestration site, to monitor the site for leaks or other deterioration of storage integrity over time, and to verify that the CO₂ is stored and non-harmful to the host ecosystem. MM&V capability will ensure safe permanent storage, reduce the risk associated with buying or selling credits for sequestered CO₂, and help satisfy regulators and local government officials who must approve large sequestration projects. MM&V will also provide valuable feedback for continual refinement of injection and management practices.

Migration of CO₂: The movement of CO₂ through a geologic formation, driven by density or a pressure differential.

Mineral Carbonization: A process in which CO₂ reacts with magnesium or calcium oxide to form mineral carbonates. The mineral carbonates are non-reactive solids - highly permanent carbon storage.

Oxygen Combustion: An approach to fossil fuel conversion in which the fuel is combusted in pure oxygen rather than air, which is 78% nitrogen and 21% oxygen. Oxygen combustion systems exhaust a stream of highly pure CO₂ as an inherent part of their operation.

Placement (of CO₂ in geological structures): The physical injection of CO₂ into geological structures.

Post-Combustion Capture: A system for CO₂ capture from a fossil fuel conversion where the fuel is combusted in air and resulting CO₂ is scrubbed, absorbed, or otherwise captured from the flue gas, which is primarily CO₂ and nitrogen.

Pre-Combustion Capture: A system for CO₂ capture from a fossil fuel conversion where the fuel is decarbonized via gasification, pyrolysis, or reforming prior to combustion. The synthesis gas from decarbonization is primarily a mixture of CO₂ and hydrogen. The CO₂ is captured from the hydrogen before the hydrogen is combusted.

Reservoir: A subsurface, porous, permeable rock body surrounded by impermeable rock and containing oil, gas, or water. Most reservoir rocks consist individually or collectively of limestone, dolomites, or sandstone.

Saline aquifer: Geologic formation of porous rock that is filled with brine - a solution of water and salt (sodium chloride), usually containing other salts also. Ocean water contains 3% salt. Brines in underground formations (i.e. saline aquifers) can contain 20% salt or more. Brine must be desalinated before it can be used for drinking, and underground formations containing brines are not regarded as drinking water supplies.

Sequestration (of CO₂): The capture and long-term storage of carbon dioxide that would otherwise be emitted to the atmosphere. CO₂ can be captured at the point of emission, or they can be removed from the air. The captured gases can be stored in geological formations, dissolved in deep oceans, converted to rock-like solid materials, or contained in trees, grasses, soils, or algae.

Storage (of CO₂ in geological structures): The placement and retention of CO₂ in geological formations for the purpose of long term retention from the atmosphere.
