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CARBON CAPTURE AND LONG-TERM STORAGE: ANALYSIS OF 2010 SURVEY

Series on Chemical Accidents
No. 26

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FOREWORD

This document contains the analysis of a survey performed in 2010 regarding carbon capture and long-term storage (CCS). CCS involve capturing the CO_2 emitted when burning fossil fuels, transporting it and storing in secure spaces such as geological formations, including depleted oil and gas fields and aquifers (natural underground reservoirs).

The objective of this survey was to enable member countries to: (i) share knowledge and understanding of the hazards of CO_2 sequestration and the risks to human health and environmental safety; (ii) identify credible major accident scenarios, including those associated with CO_2 capture and compression, storage prior to transport and injection for geological storage; (iii) examine how these have influenced regulatory approaches, such as the application of permissioning regimes; and (iv) consider whether there is a need for further work at OECD or any other international forum.

A UK led Steering Group (SG-CCS) was established in 2009, involving experts from Canada, France, Germany, Korea, the Netherlands, the United Kingdom, the European Commission, industry and the OECD Secretariat. The SG-CCS developed a questionnaire with the aim to identify the major hazard (health, safety and environmental) implications of CO_2 sequestration by investigating issues related to: CO_2 capture facilities; transport of CO_2 for CCS purposes; CO_2 injection facilities; emergency planning; (major) accidents; research; risk assessment; and (risk) communication.

Responses were received from thirteen countries: Belgium, Canada, Czech Republic, France, Germany, Korea, Netherlands, Norway, Slovak Republic, Sweden, Switzerland, Turkey and the United Kingdom.

This document is published under the responsibility of the Joint Meeting of the Chemicals Committee and the Working Party on Chemicals, Pesticides and Biotechnology, which has agreed that it be unclassified and made available to the public.

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PREAMBLE

1. This report of OECD's Working Group on Chemical Accidents was prepared with the Health and Safety Executive (HSE), United Kingdom (UK) in the lead, in consultation with the Steering Group for the project on the 'Risk and Regulation of Carbon Capture and Storage'. The Steering Group comprises: UK (lead), Canada, France, Germany, Korea, the Netherlands, the European Commission, BIAC (the Business and Industry Advisory Committee to the Organisation for Economic Co-operation and Development) and the OECD Secretariat.

2. Carbon capture and storage (CCS) involves capturing the carbon dioxide (CO_2) emitted when burning fossil fuels, transporting it and storing in secure spaces such as geological formations, including depleted oil and gas fields and aquifers (natural underground reservoirs). The OECD project aims to explore the approaches taken by member countries to identify the accident potential of the processes involved in CCS and the regulatory approaches taken and, if necessary, provide recommendations. It also addresses the issue of communication related to risk and regulation of CCS.

3. In 2010 the project undertook a survey to help identify the major hazard (health, safety and environmental) implications of CO_2 storage that took the form of a questionnaire on issues related to:

1. CO_2 capture facilities
2. Transport of CO_2 for CCS purposes
3. CO_2 injection facilities
4. Emergency planning
5. (Major) accidents
6. Research
7. Risk assessment
8. (Risk) communication

4. Responses were received in 2010 from thirteen countries: Belgium, Canada, Czech Republic, France, Germany, Korea, Netherlands, Norway, Slovak Republic, Sweden, Switzerland, Turkey and the United Kingdom.

INTRODUCTION

5. CCS, or Carbon Capture and Storage, is a low carbon technology which captures carbon dioxide (CO_2) from the burning of coal and gas for power generation, and from the manufacturing of steel, cement

and other industrial facilities. The CO_2 is then transported for safe and permanent underground storage, preventing it from entering the atmosphere and contributing to anthropogenic climate change.

6. There are currently three main methods for **capturing CO_2**:

- **Post-combustion capture** – using amine solvents or chilled ammonia to remove the dilute CO_2 from flue gases after hydrocarbon combustion. Other post-combustion possibilities, currently being researched, include cryogenically solidifying the CO_2 from the flue gases, or removing CO_2 with an adsorbent solid, or by passing CO_2 through a membrane.

- **Pre-combustion capture** - removing CO_2 prior to combustion, to produce hydrogen. Hydrogen combustion produces no CO_2 emissions, with water vapour being the main by-product.

- **Oxy-fuel combustion** - burning fossil fuels in pure oxygen as opposed to air resulting in a more complete combustion. This results in an exhaust stream which consists of almost pure CO_2 (typically 90%) and water vapour, which can be easily separated from the CO_2 by condensation.

7. CO_2 capture will only be economic at large point sources of CO_2 such as power stations and large industrial plants. In most cases these will not be near to a suitable underground reservoir for storing the CO_2 and therefore the CO_2 will have to be transported either by pipeline or ship in supercritical or dense (liquid) phase.

8. The final stage of CCS is injecting into a geological formation (Depleted Oil and Gas Reservoirs, Deep Saline Reservoirs or Deep Unmineable Coal Seams) where it will not be in contact with the atmosphere for thousands of years.

9. CCS is viewed globally as a key carbon abatement technology. The International Energy Agency (IEA), Blue Map Scenario[1] illustrates how energy technologies may be transformed by 2050 to achieve the global goal of reducing annual CO_2 emissions to half that of 2005 levels. Within this scenario CCS delivers one fifth of the lowest-cost greenhouse gas reduction solution in 2050. These reductions will require deployment of CCS on a massive scale – 18 projects by 2015, 100 projects by 2020, 850 projects by 2030 and 3,400 projects by 2050.

10. The Risk and Regulation of Carbon Capture and Storage Project aims to:

- Share knowledge and understanding of the hazards of CO_2 capture, transport and storage and the risks to human health, safety and the environment.

- Identify credible major accident scenarios across the CCS process chain and examine how they have influenced regulatory approaches and

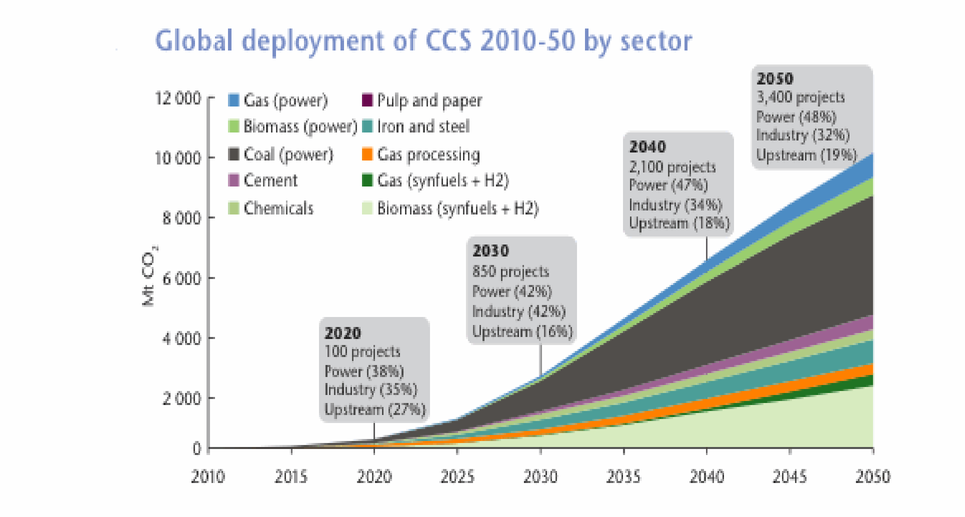
- Consider whether there is a need for a consistent international approach to regulation.

11. This report summarises the detailed answers to the questionnaire from thirteen countries: Belgium, Canada, Czech Republic, France, Germany, Korea, Netherlands, Norway, Slovak Republic, Sweden, Switzerland, Turkey and the United Kingdom. Responses from three of these countries were brief, for reasons such as the responsibility for CCS was not recognised or the questions were not applicable. Some developing countries are at very early stages of investigating CCS potential with no clear

[1] International Energy Agency, Energy Technology Perspectives 2010 – Strategies & Scenario to 2050

responsibilities assigned as yet and hence were often unable to complete the questionnaire on behalf of the country.

Figure 1. Global deployment of CCS 2010-50 by Sector



Source: IEA CCS Technology Road Map 2009

12. The following analysis is considered under headings which broadly follow the structure of the questionnaire:

- CCS deployment
- Legal frameworks and technical standards
- Land use planning
- Emergency planning
- Major accidents
- Research
- Risk assessment
- Risk communication

13. Given the limited number of responses and the geographical distribution of the responding countries the analysis is supplemented by a limited review of publically available information from countries currently leading in CCS (principally America and Australia), the Global Carbon Capture and Storage Institute (GCCSI) and the IEA.

CCS DEPLOYMENT

Questions posed

1. CO_2 Capture Facilities

a) Has your country identified sites for Carbon Capture Ready generating stations, or are carbon capture facilities already operating?

2. Transport of CO_2 for CC purposes

a) Is CO_2 for CCS currently transported in your country? If so, by what mode, and how much CO_2 it transported per annum for each of the following options: pipeline – ship – train

b) Concerning CO_2 pipelines, general facts: how many pipelines, what length in total, how old (range from ... to ...), operation pressure (range from ... to ...), diameter (range from ... to ...), depth of cover (range from ... to ...), volume of CO_2 transported per annum?

c) Do CO_2 pipelines cross sensitive areas like densely populated areas or areas of environmental importance? Provide details

d) If new pipelines are planned for CCS projects, explain how much of the information do you have on them.

3. CO_2 Injection Facilities

a) Is your country intending to inject CO_2 into strata: offshore – onshore – for enhanced oil recovery (EOR)?

Analysis

14. The survey results revealed a mixed picture of CCS deployment with just fewer than half the respondents not having identified potential carbon capture ready generating stations or carbon capture facilities already operating.

15. Experience of large scale CO_2 transport in Europe is limited. CO_2 is transported by road for traditional industrial uses. Germany also transports small amounts of CO_2 by road for the pilot CCS projects. France, the Netherlands, Norway and Turkey transport CO_2 by pipeline with the Netherlands transporting CO_2 through densely population areas.

Table 1. Experience of large scale CO_2 transport

	Length	**Age**	**Operating pressure**	**Diameter**	**Depth of cover**	**Volume CO_2/yr**
Canada						
France	29 km pipeline	30 yrs		200-300 mm	1.4 m	60,000 tonnes
Germany	133 km proposed pipelines					

Netherlands	97 km main pipeline + 130 km distribution pipelines		8-22 bar	660 mm		300,000 tonnes
Norway	120 km pipeline	2005		200 mm	approx 1 m	1M tonnes
UK	Scoping studies for pipeline networks (Yorkshire/ Humbersid, Tees Valley, Merseyside, …)					

16. Finally the survey indentified whether current or proposed CO_2 injection activity was on or offshore.

Table 2. Onshore/ Offshore CO_2 injection activity

Onshore only	***Offshore only***	***Both***	***Enhanced Oil or Gas Recovery***
Belgium	Norway	France	Czech Republic
Czech Republic	United Kingdom	Germany — in their response Germany said they had no specific applications for offshore storage but that it was in their strategic plans	Korea
Slovak Republic		Korea	Netherlands
Turkey[2]		Netherlands	Turkey
		Sweden	United Kingdom — the UK has no specific plans for EOR but considers EOR likely

17. As stated in the introduction, given the limited number of responses and their geographical spread this collective data is only a partial representation of global CCS activity. In particular, it underestimates the experience of CO_2 transport by pipeline which is concentrated in North America. Pipeline transport of CO_2 for EOR began 40 years ago and there is now nearly early 6,000 km of pipeline are transporting over 40 million tonnes per annum of CO_2. The oldest long distance CO_2 pipeline in the US is the Canyon Reef Carriers Pipeline in Texas, which is 225 km long and began service in 1972. For more economical transport, CO_2 is typically compressed to a pressure near 2,200 psi (15.2 MPa) to operate in the liquid and supercritical CO_2 phases at ambient temperatures and high pressure. Most of the pipelines have booster pumping stations to compensate for pressure drop along the length of the pipeline. While such a pipeline infrastructure sounds significant in size, it needs to be compared with the approximately 800,000 km of pipelines in the US used to transport natural gas and hazardous materials.

[2] In Turkey, there is onshore (on land) CO2 injection activity. This information was not available at the time of the analysis of the survey.

18. For an up to date analysis of global CCS deployment, the Global Carbon Capture and Storage Institute (http://www.globalccsinstitute.com/projects/map) and the Scottish Centre for Carbon Capture and Storage (http://www.sccs.org.uk/storage/globalsitesmap.html) both maintain interactive maps recording CCS projects with sufficient detail to determine their scale, status (in planning, operational, cancelled etc.) and the technology being used.

19. The GCCSI's Report [3]on the Status of CCS Projects (covering capture, transport and injection) records that active collaboration between government and industry has led to:

- 74 large-scale integrated projects (LSIPs) at various stages of the asset lifecycle, an increase since 2009 but a small net reduction from the figures reported in 2010;
- eight operating large-scale projects and six in the execute stage;
- 60 potential projects in various stages of development planning:
  - 24 projects at the defining stage (most mature);
  - 28 projects at the evaluate stage (moderately mature); and
  - 8 projects at the identify stage (least mature)"

20. CCS remains a relatively immature technology with first generation full chain CCS projects still at demonstration stage. It is worth noting from the GCCSI interim report 2010[4] that whilst there were 44 projects planned for the power sector, there were only nine operational fully integrated CCS projects and all of these (plus the two fully integrated projects under construction at the time) were linked to the oil and gas sector. Although progress can be shown in the pace of CCS uptake it is increasingly clear that the IEA's global deployment targets of CCS 2010-2050 may not be achievable.

21. The 2011 December update from GCCSI[5] reported the cancellation of key projects in Europe:

- The cancellation of the **Longannet Project** (Scotland) was announced in October 2011, following a decision by the UK Government not to fund the construction of the project. The UK Government remains committed to CCS.
- The **Vattenfall Jänschwalde** (Germany) project cancelled in December 2011, due to a lack of progress in resolving regulatory issues around CCS in Germany, particularly with respect to the permanent sequestration of CO_2 underground. There are now no large scale projects planned in Germany.

[3] Global CCS Institute, Global Status of CCS:2011

[4]Global CCS Institute, The Status of CCS Projects Interim Report 2010

[5] Global CCS Institute, Global Status of Large-scale Integrated CCS Projects: December 2011 Update

LEGAL FRAMEWORKS AND TECHNICAL STANDARDS

Questions posed

1. CO_2 Capture Facilities

a) What current legislative measures currently apply to these installations?

b) What current technical standards currently apply to these installations?

c) Which authorities are responsible for these installations [environment, health and safety, etc.]?

d) Do you think that there needs to be further legislation or technical standards to regulate the process of carbon capture, and possible storage of some CO2 on site? If so what is required?

2. Transport of CO_2 for CC purposes

a) Is there a legal framework for the transport of CO2 in pipelines? If yes, give details

b) Are there any technical guidelines which have to be considered (or should be considered) when planning and operating CO2 pipeline? If yes, give details; in particular, is there any guidance/regulation concerning the level of impurities which may be present in the CO2 pipelines?

c) Which authorities are responsible for CO2 transport [environment, health and safety, etc]?

d) Are CO2 pipelines regulated, or have technical guidelines, separately from pipelines for other substances? If so please give specific details.

e) Are there any regulations covering transport ofCO2 for CCS (Ship, Train or others)? If yes, give details.

3. CO_2 Injection Facilities

a) What (safety) regulations apply to the injection process?

b) Once the long term storage operation is completed and the site sealed off, do the safety authorities – or other authorities have any involvement in long term monitoring of the site?

c) What methodology do you use or intend using for purposes of monitoring, reporting and verification of CO2 captured and stored?

Analysis – Legal Frameworks

22. Regulatory responsibility for CCS in relation to human health, safety and environment varies greatly across the survey respondents but in general they reflect the existing structures for the regulation of industrial activities.

23. Given the geographical spread of the survey responses most cited the EU Directive 2009/31/EC[6] (known as the 'CCS Directive') as the primary legislation covering CCS. European Union (EU) Member States had until 25 June 2011 to transpose the Directive into their respective national laws. Whilst the Directive focuses primarily on the storage aspect of CCS, it does briefly address the capture and transport elements.

Capture[7]

24. The capture process of CCS will primarily be regulated through incorporation within the EU's Integrated Pollution Prevention and Control (IPPC) Directive (Art 37). IPPC imposes a permitting regime on a range of specified industrial activities, controlling the release of contaminants into air, water and land. As such, all operators of capture installations will be required to obtain a IPPC permit, which will demand the use of 'best available techniques' (BAT) for CO_2 capture, impose clean-up requirements in cases of unauthorised release and site closure, and involve important rights to public participation (Arts 3, 9 and 15 IPPC). Operators will also be required to carry out an assessment of the likely significant effects on the environment of any capture facilities in accordance with the provisions of the Environmental Impact Assessment (EIA) Directive (Art 31). Importantly, public consultation will be required, and the assessment carried out must be taken into account when permitting the facility under IPPC.

Transport

25. Overall, the CCS Directive leaves many aspects of CCS transport to be regulated at Member States level relying on national pipeline regulations and property and planning laws together with existing European legislation including the express inclusion of the transport phase within the scope of the Environmental Impact Assessment (EIA) Directive.

26. The Directive deals with third-party access to both transport networks and storage sites calls for restrictions on the composition of CO_2 streams, to take account of the risks that contamination might pose to the safety and security of the transport and storage network, and to the environment and human health.

Storage

27. The Directive sets out specific requirements for: site selection and exploration; storage permits (applications, contents and conditions); operation; (including CO_2 stream acceptance criteria, monitoring, reporting, routine and non-routine competent authority inspections, corrective measures); financial security and closure, post-closure and transfer of liability.

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[6] Directive 2009/31/EC of the European Parliament and of the Council of 23 April 2009 on the geological storage of carbon dioxide and amending Council Directive 85/337/EEC, European Parliament and Council Directives 2000/60/EC, 2001/80/EC, 2004/35/EC, 2006/12/EC, 2008/1/EC and Regulation (EC)

[7] Since the questionnaire was distributed in 2010, the IPPC Directive has been superseded by the Industrial Emissions Directive 2010/75/EU (IED) which is to be implemented within the EU Member States by 7th January 2013. Whilst the IED requires that best available techniques (BAT) for CO2-capture are applied there is as yet no BAT Reference (BREF) document available. In addition the development of such a document is not currently listed within the 2013-2018 BREF work programme. On average the development of a BREF document takes around 3 years and a transition period of up to 4 years for existing installations under the IED regime is foreseen, therefore the establishment of a meaningful BAT for carbon capture is unlikely within the foreseeable future.

28. The European Commission has published a series of guidance documents on some of the more technically demanding aspects of the regime. These documents cover: the CO_2 storage life cycle risk management framework; characterisation of the storage complex, CO_2 stream composition, monitoring and corrective measures; criteria for transfer of responsibility to the competent authority; and financial security and financial mechanisms.

29. In relation to **national legislation** for the survey responders (outside the scope of the CCS Directive) seven countries had no specific legal framework for the transport of CO_2 in pipelines. The Czech Republic and Norway had legislation in preparation. In France and the Netherlands transportation of CO_2 in pipelines is covered by existing legislation. Korea believes a similar framework to that used for Liquefied Natural Gas (LNG) pipelines could be used. The UK has reviewed its approach to pipeline safety regulation.

30. The IEA publishes a CCS Legal and Regulatory Review[8] based on contributions from various governments and other organisations which is available on their web site. To introduce each edition, the IEA provides a brief analysis of key advances and trends.

31. The main legal frameworks for the US, Australia and Canada are summarised below.

Table 3. Legal Frameworks: United States, Australia, and Canada

Country	Legislation
US	• IOGCC Guidelines • American Clean Energy and Security Act • EPA Guidance under the Underground • Injection Control Programme 2007 • State regulations from Wyoming, North Dakota and Montana
Australia	• Australian Regulatory Guiding Principles • The Offshore Petroleum Amendment (GHG Storage) Act 2008 • Australian Greenhouse Geological Sequestration Act 2008 Queensland Greenhouse Gas Storage Act 2009-08-28 The Barrow Island Act of 2003 • related to Gorgon
Canada	• *Canadian Environmental Protection Act*, *1999* • Alberta has well-developed regulatory frameworks in the oil and gas sector that are applicable to CCS projects. • British Columbia has a mature oil and gas industry supported by

[8] Carbon Capture and Storage: Legal and Regulatory Review (Edition 1) *2010*

	a strong regulatory framework that is applicable to CCS development. • Saskatchewan has an existing regulatory framework that accommodates CO_2 injection.

32. To compliment this review the IEA have published a CCS Model Regulatory Framework[9] which draws on existing regulatory frameworks to propose key principles (based on current approaches) for handling regulatory issues associated with CCS. The framework highlights both occupational health and safety and civil projection (the risks presented to human populations located in the vicinity of CO_2 capture, transport and storage facilities) as key areas where existing national legislation may need to be extended to cover CCS operations.

33. The survey results do not offer a unanimous view as to whether or not additional legislation or the extension of existing legislation is required to address the health and safety aspects of CCS. For example, the agreed approach in the UK, following their regulatory review, is to apply the general principles of the major hazard safety regimes for the early demonstration projects whilst the evidence and knowledge base for handling large volumes of CO_2 is developed.

34. The GCCSI published a CCS Regulatory Test Toolkit in February 2011 (produced by the University of Edinburgh on behalf of the Scottish Government) to ensure best practice in developing regulations and permitting processes around CCS projects. The toolkit applies to the full process chain and covers health, safety and environmental issues.

Analysis – technical standards

35. The survey results provided limited detail on available technical standards for CCS.

36. A wider review of available information revealed considerable activity in this area as a number of projects are underway or have been completed to produce best practice guidelines, based on current knowledge, for handling CO_2 for CCS. Examples for readily available guidance are included below (It should be noted that this guidance does not have any legally binding character):

- DNV (Det Norske Veritas) - **Qualification Procedures for CO_2 Capture Technology -** systematic procedure that explains in detail how to identify, describe, and manage risks with the implementation of new CO_2 capture technology in a quantitative way by following a set of sequential steps known as the qualification process.

- DNV - D**esign and Operation of CO_2 Pipelines -** guidance for managing risks and uncertainties during the whole lifetime of a CO_2 pipeline, including design, testing, inspection, operation, maintenance, and de-commissioning. The document incorporates lessons learned from existing CO_2 pipelines.

[9] International Energy Agency, Carbon Capture and Storage: Model Regulatory Framework 2010

- DNV - **Guidelines for CO_2 injection and geological storage of CO_2.**

- US Pipeline Standards – US Federal Regulations: Transport of Hazardous Liquids by Pipeline. In the USA, CO_2 pipelines are classified by the Office of Pipeline Safety of the United States Department of Transportation as High Volatile/Low Hazard and Low Risk. **The Code of Federal Regulations, Part 195: Transport of Hazardous Liquids by Pipeline**, specifically covers issues relating to the transportation of **hazardous liquid or carbon dioxide**. The regulations listed in Part 195 are comprehensive and represent US pipeline industry best practice. US Federal pipeline safety regulations are framed to ensure safety in design, construction, inspection, testing, operation and maintenance of pipelines. In addition, they set out procedures for administering pipeline safety programmes and incident response plans. Similar regulations are in place in Canada.

- US CCS Guidelines - Guidelines for CO_2 Capture, Transport, and Storage. The World Resources Institute (WRI) has produced a set of "Guidelines for Carbon Capture and Transport."

  – Capture Guideline 1: Recommended Guidelines for CO_2 Capture

  – Capture Guideline 2: Recommended Guidelines for Ancillary Environmental Impacts from CO_2 Capture

  – Transport Guideline 1: Recommended Guidelines for Pipeline Design and Operation

  – Transport Guideline 2: Recommended Guidelines for Pipeline Safety and Integrity

  – Transport Guideline 3: Recommended Guidelines for Siting CO_2 Pipelines

  – Transport Guideline 4: Recommended Guidelines for Pipeline Access and Tariff Regulation

37. In 2011 the International Organisation for Standardisation Technical Committee (ISO/TC67) *Materials and Equipment for the Oil and Natural Gas Industries* committee considered a proposal to create a new ISO Technical Committee to develop standards for CCS covering capture, transport, storage, risk and quantification/verification. Although such a proposal is welcome there is concern amongst the CCS stakeholders that it is too early to develop an international standard in light of the current knowledge gaps associated with the behaviour of supercritical CO_2 (see research section).

38. The development of internationally recognised standards would facilitate the wide spread deployment of CCS and in particular the development of trans-boundary networks. Work on an international standard for '*materials, equipment, environmental planning and management, risk management, quantification and verification, and related activities in the field of carbon capture and storage (CCS)*' will begin in 2012. The committee will be chaired by Canada and China with a further 11 countries participating and 12 countries observing.

LAND USE PLANNING

Questions posed

1. CO_2 Capture Facilities

f) Have you considered the implications of this activity for the land use planning policy? If so, give details

2. Transport of CO_2 for CC purposes

j) Are CO_2 pipelines (particularly) considered in the land use planning policy?

k) Are areas where earthquakes are possible considered in guidelines/regulations? If yes, please give details.

Analysis

39. Four countries, France, the Netherlands, the Slovak Republic and the UK had considered the implications for Land Use Planning at capture sites. In these cases Land Use Planning was controlled under existing legislation. Belgium cited article 9a of the EU Directive 2001/80/EC[10], as amended by article 33 of EU Directive 2009/31/EC, which provides for power plants of greater than 300 megawatts capacity licensed after 25 June 2009 to set aside space for CCS. The Czech Republic said that some comments and actions were possible at municipality and county level. Germany referred to the Seveso II Directive[11], which imposes land use planning requirements in relation to establishments subject to the Directive (Article 12). However CO_2 is not a dangerous substance within the meaning of Seveso II, although some power plants may already be subject to Seveso II owing to the presence on site of other dangerous substances such as ammonia. At the moment it is not clear if CCS plants could fall into the scope of the Seveso II Directive due to substances like (chilled) ammonia, oxygen or hydrogen. Germany also pointed out that E.ON makes provision for future carbon capture retrofit in planned power plant projects. Norway and Korea had not considered land use planning issue yet.

40. It is not clear to what extent land use planning has been considered as a safety issue by the correspondents in relation to capture facilities.

41. Most countries responding to the survey do not consider CO_2 pipelines in land use planning policy. France would treat a CO_2 pipeline like any other pipeline carrying a dangerous fluid; the Netherlands will do so from 2011. If the UK review of the Pipelines Safety Regulations 1996 concludes that CO_2 should be a dangerous fluid, then the land use planning legislation would apply as a consequence. In Germany transport pipelines are considered at various stages of planning at the Lander level but this does not seem to be related to control the risks to neighbouring properties; however the route of any CO_2 pipeline related to a CCS installation would be taken into consideration in applying planning guidelines to the CCS installation in question.

42. Apart from France none of the respondents appear at present to have legislation in force relating to land use planning to control risks from CO_2 pipelines, although in the Netherlands legislation which will

[10] Directive 2001/80/EC of The European Parliament and of the Council of 23 October on the limitation of emissions of certain pollutants into the air from large combustion plants

[11] Council Directive 96/82/EC of 9 December 1996 on the control of major-accident hazards involving dangerous substances.

come into force in 2011 will implement land use planning around pipelines transporting dangerous substances (including CO_2). The UK position will be determined by the outcome of the review of the Pipelines Safety Regulations.

43. In France the legislation defines areas of seismic risk; in these areas seismic risk would have to be considered in a pipeline risk assessment. In the Netherlands mining legislation considers land subsidence but serious earthquakes are considered extremely unlikely. In Norway seismic risk would be taken into account in the design. In the UK the general duties under the Pipelines Safety Regulations 1996 require, among other things, that external forces be taken into account in the design of a pipeline.

44. Further consideration of land use planning policies around facilities handling CO_2 on a large scale should be informed by ongoing research into the hazard range of CO_2 following the catastrophic failure of a pipeline or vessel.

EMERGENCY PLANNING

Questions posed

1. CO_2 Capture Facilities

g) Have you considered the implications for emergency planning – if so, give details.

4. Emergency Planning

Analysis

45. The Czech and Slovak Republics intend to cover emergency planning under proposed new legislation. France proposes to put in place around CCS facilities an emergency plan along Seveso-directive lines. In the Netherlands it is believed to be covered by existing legislation relating to dangerous substances. In the UK it has been considered for pipelines: if the Pipelines Safety Regulations are amended and the CO_2 pipelines become major hazard pipelines, emergency planning will have to be considered[12]. However these regulations would not apply to carbon capture installations.

46. Although most countries seem to have considered emergency planning it is not clear how much consistency there has been in approach. France proposes to put in place around existing facilities off-site plans based on the Seveso approach, the UK is proposing to put in place emergency plans in the vicinity of CO_2 pipelines and it is not clear what the Czech Republic proposes, although it is drafting legislation.

47. There would seem to be very little in the way of specifications for CO_2 emergencies. Germany gave the most detailed response, in particular in relation to mining. Although some of this information might be generally applicable some of it probably will not be.

48. As with land use planning arrangements, the development of any guidance on emergency response should be informed by ongoing research into the hazard range of CO_2 following the catastrophic failure of a pipeline or vessel.

[12] Since the UK responded to this survey HSE is now reviewing the proposed regulatory approach to pipeline safety following the Coalition Government's new approach to legislation.

MAJOR ACCIDENTS

Questions posed

5. Major Accidents

a) Are there any experiences with accidents involving CO_2 that happened in the past whether in connection with CCS or other operations involving CO_2? How many accidents, Short description of the accidents/incident (causes, consequences)

b) What lessons should be learned from these accidents/incidents?

c) What would you consider to be a critical quantity of CO_2 in terms of its capability of causing a major accident (e.g. 50t, 200t, 500t, 5000t, more, less?)

Analysis

49. CO_2 has been recognised as an industrial hazard for over 100 years. Several countries reported no or only minor incidents. Germany and the UK reported several serious ones, although most of those mentioned by the UK had occurred abroad. Korea had had one serious incident and the Netherlands had had an incident that killed some ducks (it is not known whether the ducks were of an endangered species and therefore whether the incident would have constituted a major accident to the environment had CO_2 been covered by Seveso II). None of the incidents were associated with CCS and therefore should not be read as a list of credible accident scenarios although they do give an indication of the hazard potential. A summary of the incidents reported is at table 4 (p. 26).

50. In respect of lessons learnt from these incidents, six countries either did not respond or replied "Not applicable". Generally, comments from the other countries showed that the hazards of CO_2 need to be taken seriously. France considered the hazard from a toxic cloud of CO_2 to be the most important problem with CCS. The UK commented that CO_2 is not a simple asphyxiant and that primary containment standards are very important (and need to be developed for CCS processes). As it is heavier than air, CO_2 will tend to accumulate in depressions etc. This should inform emergency response planning. Pits etc should be subject to confined entry procedures. The Netherlands was concerned about the need to improve the integrity of smaller pipelines and Korea noted that a high-concentrated leak of CO_2 can cause people significant harm. Germany commented that lessons can be applied from experience in the mining industry where developments have been made in technological/ organisational control measures, training and emergency planning.

51. There is, therefore, some information available on experience in other areas that can inform approaches to prevention, control and mitigation of CO_2 accidents.

52. There was no consensus on defining a critical quantity of CO_2 in terms of its capability of causing a major accident. Most countries said this would be dependent on one or more factors and mentioned: weather and diffusion conditions, temperature, shape of the landscape, storage conditions, quantity, concentration, pressure and density of settlements. Three countries did not respond. Germany commented that, in a mine, even a quantity of less than 50 tonnes could cause a serious accident.

53. Switzerland stated that no numerical value provides a suitable indicator for a critical quantity of causing a major accident. They suggested applying an analytical process known as a Hazards Effect Management Process (HEMP), taking account of factors that would contribute to the risk (such as enclosed cellars or spaces where CO_2 might accumulate) as well measures that would reduce the risk. They argued that applying a single numerical value was not a suitable approach to managing the risk. However, other

things being equal, the possible extent and severity of a major accident increases with increasing quantity of dangerous substance. There needs to be some form of screening for determining the point at which more detailed assessment of the risk and control measures is warranted.

Table 4. Reported Incidents Involving CO_2

Country	Year	Amount of CO_2 released	Cause	Natural cause?	Number affected	Fatalities	
France			CO_2 pipeline leak at chemical site		0		
France			CO_2 bottle breakage at amusement park		2		
France			CO_2 bottle leakage at amusement park		4		
Germany	2008	40t	CO_2 fire extinguishing system activated		107		
Germany	2006	10kg	Open valve on compressed gas cylinder in a small cellar		3	2	
Germany	1908		Potash Mining. Underground gas and salt blowouts - CO_2 spread to surface and settled in valleys				
Germany	1953		Gas mixture with high CO_2 content spread from a mine into 5km of valley			3	
Germany	2008		CO_2 poisoning in potash mine			1	
Germany	1911		Eruption from CO_2 drill hole			1	
Korea	2001		Leak of CO_2 used for fire extinguishing		60*	1	* suffocated
Netherlands			Pipeline leakage caused by bad weld discovered after several weeks of accumulation			Ducks	
UK			Dispensing CO_2 from tractor-trailer			1	
UK	1994		Opening pressure vessel still under pressure in near supercritical fluid process - pressure threw victim across the room			1	
Hungary	1998		High pressure gas containing CO_2 from an oil well formed a cloud and blown by the wind		2500 evacuated		
Spain			Blow out during drilling of a well - produced 2 large craters 70m from the wellhead	Natural			
Indonesia	1979	200,000 t	CO_2 emissions prior to eruption of a volcano	Natural	149*		*asphyxiated
Cameroon	1984		Sudden release of volcanic CO_2 from Lake Monoun	Natural		37	
Cameroon	1986	1.24MT	Release of CO_2 from Lake Nyos	Natural	1700*		*asphyxiated
USA		16Mt per year	Diffuse degassing from Yellowstone hydrothermal areas means CO_2 percolates through porous zones to the surface	Natural			
USA			CO_2 emerged along ground faults at Horseshoe Lake following seismic activity killing trees	Natural			
Italy			Increased seismic activity	Natural		Animals	
USA			CO_2 seepage results in CO_2 charged groundwater in springs and old well bores	Natural			

Hungary	1992	Leakage as a result of permeable cap rocks	Natural?	2	
UK		Employee overcome by release in CO_2 recovery plant at a brewery			1
UK	1995	CO_2 venting from abandoned coal mine due to low pressure outside	Natural		1
		CO_2 from evaporation of blocks of dry ice accumulating in a walk in freezer			1
		Oxygen displacement by CO_2 in decorative waterfalls		2	
Canada		Descaling a water well with strong acid which reacted with carbonate deposits			2
Canada		Lack of oxygen when entering covered well not used for 10 yrs - may be due to any gas		1	
USA	1998	Sudden discharge of CO_2 fire suppressant system during routine maintenance		15	1
		Cross country skier found dead in snow cave - CO_2 levels of 70% - degassing of magma below the ski area	Natural?		1

RESEARCH

Questions posed

6. Research

a) Are there any completed or on-going research projects in your country on the safety problems of CO_2 for CCS e.g. on capture technology (for example what quantity of CO_2 is present at capture facilities); pipelines; human health/toxicity; concentration of impurities in the CO_2; materials used for pipelines/plants; and quantities of dangerous substances that could be present in conjunction with CO_2 capture facilities (e.g. H_2, O_2, CO, NH_3, methanol,H_2S)?

b) Does the research concentrate on any particular areas e.g. transport, storage, etc?

c) If yes to a) and b) above, give details.

Analysis

54. Several countries reported research on a range of subjects but in general terms CCS research relating to human health and safety tends to focus on pipeline transport.

55. Element Energy's study "Global CCS Pipeline Infrastructures" "prepared for the IEA in 2010 identified four main technical issues that required attention:

"The first technical issue is that long distance CO_2 transport is likely to involve supercritical or dense phase transport across more challenging terrains (e.g. close to urban centres and offshore) than has largely been the case historically. Existing engineering and regulatory guidelines and experience worldwide (and particularly outside of the US or Norway) are therefore limited."

"The second technical issue is that even 'overwhelmingly pure' CO_2 streams from capture plants are likely to have levels of impurities that have the potential to impart different physicochemical properties to the CO_2 and increase the engineering design complexity compared to existing CO_2 pipelines. Very few engineers and safety professionals worldwide currently have the skills and experience to make informed decisions on appropriate designs (e.g. levels of impurities) for the safe transport of captured CO_2."

"The third technical issue is that, unlike CO_2 transported from naturally occurring sources for enhanced oil recovery, the amount of CO_2 from power and industrial sources are likely to be variable. This will necessitate careful management of CO_2 flow to avoid phase changes within the pipeline. Guidance on management of intermittency in CO_2 pipelines is extremely limited."

"Fourth, common entry specifications for CO_2 pressures, temperatures and concentrations of impurities would be required where multiple CO_2 sources connect to the same pipeline network. This could impact the choices (and costs) of capture, compression and drying technologies. CO_2 sources may not always be able to disclose details of their capture technologies and, implicitly, their business plans. This may be through lack of certainty or for commercial or competition reasons. In these cases, a storage-led or transport-led company, rather than a capture-focussed company, may seek to define entry specifications. Where a transport or storage-led focus does emerge, this may restrict capture technology choices (and thereby have an impact on innovation, costs and CO_2 volumes). As an example, significant oxygen impurities from oxy-fuel capture may be incompatible with CO_2 storage coupled to enhanced oil recovery. Alternatively, the resulting incremental purification costs to reduce impurity levels to allow sources using different capture technologies (e.g. pre-combustion and oxy-fuel) to connect to the same pipeline network may be less than the costs for each source to construct or develop its own transport solution."

56. As a result of these areas of uncertainty, research topics focus on the following areas:

- **CO_2 harm criteria** – The Netherlands replied that they were conducting research into the acute toxic effects of CO_2 and modelling releases from pipelines. They referred to their web site http://co2-cato-nl/cato-2/program-overview. The UK have published 'dangerous toxic loads' on the Health and Safety Executive web site based on the assessment of toxicological studies in humans.

- **CO_2 dispersion modelling** – for supercritical CO_2 including the impact of impurities etc.

- **CO_2 corrosion** - including the impact of impurities over and above water etc.

- **Fracture management** – steel strength required to prevent fracture propagation, crack arresters etc.

57. Details of the all the current and completed research projects are too numerous to list here although the more detailed questionnaire responses from Germany is included at Annex 1.

58. On a regional level, the CCS research community is well organised with a number of knowledge transferring networks supporting the exchange of information. The Carbon Sequestration Leadership Forum is currently undertaking a substantial project to map the ongoing and completed research activities on a global level. Its purpose is to aid knowledge transfer and identify any gaps in the research where further work is required. It is not clear at this stage what the level of detail that this project will deliver but if at a sufficient depth where safety specific issues can be identified it will be an invaluable tool informing the development of future standards, guidance and where appropriate, regulation.

RISK ASSESSMENT

Questions posed

7. Risk Assessment

a) Do you have any experience of risk assessments of CO2 for CCS for: a) Pipelines; b) Capture plant; c) Injection facilities d) Storage?

Analysis

59. France, Germany, the Netherlands and the UK reported research experience in parts or all of the above. Norway had research experience in pipelines. Belgium reported some experience in storage and Switzerland in acceptance criteria. Other countries reported no research experience in risk assessment of CO_2 for CCS. A more detailed summary of the responses to this section can be found at annexes 2(i) and (ii).

60. Most of the countries active in this field or about to become active have experience of risk assessment in at least some aspects. However some, the Czech and Slovak Republics and Korea, had none and others had limited experience in some aspects, such as injection. This suggests there is a case for pooling knowledge in this area.

61. DNV are currently leading a joint industry project to develop guidelines on "Effective Risk Management of Safety and Environmental Major Accident Hazards from CCS CO_2 Handling Systems". The joint industry project (JIP) includes representation from across Europe and the US as well as the GCCSI and the IEA Green House Gas R&D Programme.

RISK COMMUNICATION

Questions posed

8. Risk Communication

a) Is the public being informed about plans for new and/or the operation of existing CO2 capture, transport and storage facilities? If yes, how?

b) Have any concerns been raised by the public or public organisations about the safety aspects of CCS projects? If yes, what has been your experience? What are the main concerns of people?

c) It there any possibility for the public to participate in the decision making process regarding CCS projects? If yes, how? In what way are the remarks made by the public addressed by the competent authority? Does the competent authority react in any way on remarks made by the public? If yes, in what why? Do the official decision documents contain a chapter on communication with the public and/or remarks made by the public?

d) Lessons learned for other/future projects?

Analysis

62. Risk Communication is becoming a critical area in the deployment of CCS but the responses to the questionnaire were variable.

63. At a project level, France referred to public enquiries and the use of internet web sites for disseminating information. Germany referred to dissemination of information by companies and various public authorities. Korea provides a minimum amount of information through the mass media. The Netherlands inform the public through various media including newspapers, television, the internet, public hearings and brochures. In the UK information is made freely available through several web sites, conferences etc.

64. In general terms there is limited public awareness of CCS except where really projects are planned or in operation. In France and the Netherlands, there have been public concerns about the potential health effects of CO_2 leaks from storage and in Germany there have been massive concerns around potential storage sites.

65. In France the main concerns were the possible health effects form CO_2 leaks and soil acidification due to CO_2 leakage through micro-cracks.

66. Germany's response is attached at Annexe 3. Concerns covered a whole range of issues, including health, safety and environmental concerns, geological effects and legal and political issues.

67. In the Netherlands concerns have been raised about CO_2 storage in the Barendrecht location[13]. These related to the risks from asphyxiation and toxic effects from a large release, such as might occur during injection, as well as long term effects through leakage.

68. In Norway concerns to date have been associated more with political than health, safety and environmental issues, although there had been some health concerns raised in relation to amines and their derivatives, presumably associated with carbon capture.

69. In the United Kingdom some concern has been generated by media coverage relating to the asphyxiation risk. At present there is not a large public awareness of CCS or the plans to transport high pressure CO_2 by pipeline.

70. There is little public awareness of CCS in Belgium, possibly due to a lack of information and of interest on the part of politicians and the media. Some environmental Non-Governmental Organisations (NGOs) are sceptical about CCS whereas others are more supportive. Korea has had no specific public concerns yet relating to CCS but has had public concerns about a recent oil spill.

71. Looking beyond the survey responses public perception and risk communication of CCS varies depending on the scale. At a national or global level the debate tend to focus on CCS and Climate change and the continued use of fossil fuels. Where risk communication is associated with local projects public concerns are more a balance between global concerns and local issues include personal risk perception.

72. Public acceptance is critical for CCS projects to proceed. The GCCSI CCS Map shows a number of cancelled projects which failed or are delayed because of local concerns around safety:

- **Ohio CCS project cancelled despite Department of Energy Funding** - Local officials and state representatives had increasingly opposed the project fearing it would lower property values and increase seismic activity.

http://citizensagainstco2sequestration.blogspot.com/2009/08/midwest-group-cancels-ohio-ccs-project.html

- **Barendrecht project, Netherlands cancelled** - “In Barendrecht, Van Gils ... said he’s concerned that his apartment, which is next to an elementary school and above the perimeter of the proposed storage site, may be prone to gas leaks or shifting earth.”

http://www.bloomberg.com/apps/news?pid=newsarchive&sid=apxoWWj1cCh0

- **Vattenfall’s storage project in Beeskow, Germany cancelled** - “... fear the pollutants that are about to be pumped beneath their homes could become the next Chernobyl.” "A field trial under our community is not acceptable," says Beeskow Mayor Frank Steffen. "They are experimenting with humans," says local vacation home owner.

http://www.spiegel.de/international/germany/0,1518,710573,00.html

73. A recent GCCSI report “Communicating the Risks of CCS (July 2011)” provides a comprehensive review of research into risk communication and sets out the lessons learnt.

74. Good risk management is a knowledge based approach where hazards are understood and appropriate controls measure are identified to manage risk to an acceptable level. The effective communication of human health, safety and environmental risks and the appropriate management of those

[13] Since the questionnaire was been completed the Barendrecht project was cancelled due to public concerns around safety.

risks may help to underpin public confidence in CCS. Given the global nature of modern communications it is likely that the development of internationally agreed standards may enhance this confidence.

CONCLUSIONS

75. The aim of the Risk and Regulation of Carbon Capture and Storage Project were to:

- Share knowledge and understanding of the hazards of CO_2 capture, transport and storage and the risks to human health, safety and the environment

- Identify credible major accident scenarios across the CCS process chain and examine how they have influenced regulatory approaches and

- Consider whether there is a need for a consistent international approach to regulation.

76. It is not appropriate to draw any significant conclusions on the basis of the number of responses to the questionnaire, the level of information provided and the stage of development of CCS in the respondent countries. However the following observations can be made:

1. The CCS industry is still in its infancy. With the cancellation or delay of a number of high profile projects, growth is slower than first anticipated but global commitments to the technology remain.

2. There are a number of organisations committed to knowledge sharing – both technical and legal - on global scale. Most notably, the Global CCS Institute and the IEA CCS Regulators Forum.

3. There is a significant amount of research activity into CCS. A small proportion of this research focuses on health safety and environmental issues associated with the large scale handling of CO_2.

4. The data on incidents relating to exposure to high volumes of CO_2 provides an indication of the possible consequences of a loss of containment event but there is no consensus on the major accident hazard potential of CO_2 in CCS.

5. Work on developing an International Standard for activities in the field of CCS begins in 2012. This ISO standard will include risk management.

ANNEX 1

TABLE 1: EXPERIENCE OF RISK ASSESSMENT OF CO_2 FOR CARBON CAPTURE AND STORAGE

Country	**Area of Experience**										
	Activity				**Risk Assessment**				**Damage Indicators**		
	Pipelines	**Capture Plant**	**Injection Facilities**	**Storage**	**Quantitative RA**	**Qualitative RA**	**Modelling of Accident Scenarios**	**Other**	**Human Health**	**Environ -ment**	**Others**
Belgium	No	No	No	Yes	No reply	No reply	No reply	No reply	No reply	No reply	No reply
Czech Rep.	No										
France	Yes	Ongoing	Yes	Ongoing	Ongoing	No	Yes *	No reply	Same as at Seveso sites	Same as at Seveso sites	No reply
Germany (See Annex 3, p. 95)	No	Yes	Yes	Yes	Yes	Yes	Yes	No reply	No reply	No reply	No reply
Korea	Not yet										
Netherlands	Yes										
Norway	Yes	No reply									
Slovak Rep.	No										
Sweden	No										
Switzerland	No										

* (pipeline, capture, injection facilities)/ ongoing (storage)

TABLE 2: ACCEPTANCE CRITERIA

Country	Methodology
Belgium	No reply
Czech Republic	No
France	Risk assessment and comparison with acceptability criteria.
Germany	No reply
Netherlands	Accepted methodology is laid down in rules for risk calculations and published in official documents.
Norway	No reply
Slovak Republic	No
Sweden	No
Switzerland	This topic is covered by research being carried out by the Swiss CARMA project on public perception and legal aspects of CCS (SP 5; http://www.carma.ethz.ch/c_project/subproj/sub_5).
Turkey	not applicable
United Kingdom	HSE have developed major hazards dose criteria, Significant Level of Toxicity and Significant Level of Death (SLOT and SLOD) for CO2. HSE has criteria for land-use planning advice in the vicinity of hazardous installations which are in terms of the risk of a SLOT dose. For pipelines a range of hole sizes was used. PHAST was used to model hazard ranges to SLOT criteria. Total individual risk was calculated using HSE's Toxic Risk Assessment Methodology (TRAM) which is a spreadsheet based risk calculator. Failure rates were based on hazardous liquid pipeline data following a review of available data and taking into account that CO2 pipelines have additional failure modes compared with hydrocarbon pipelines. For semi-refrigerated storage, a pre-release version of PHAST with CO2 modelling capability was used.

ANNEX 2

QUESTIONNAIRE ON CARBON CAPTURE FOR LONG-TERM STORAGE

January – April 2010

1. CO_2 Capture Facilities

a) Has your country identified sites for Carbon Capture ready generating stations, or are carbon capture facilities already operating?

b) What current legislative measures currently apply to these installations?

c) What current technical standards currently apply to these installations?

d) Which authorities are responsible for these installations [environment, health and safety, etc.]?

e) Do you think that there needs to be further legislation or technical standards to regulate the process of carbon capture, and possible storage of some CO_2 on site? If so, what is required?

f) Have you considered the implications of this activity for the land use planning policy? if so, give details.

g) Have you considered the implications for emergency planning – if so, give details

2. Transport of CO_2 for CCS purposes

a) Is CO_2 for CCS currently transported in your country? If so, by what mode, and how much CO_2 is transported per annum for each of the following options:

- Pipeline
- Ship
- Train
- Others

b) Concerning CO_2 pipelines, general facts:

- How many pipelines?
- What length in total?
- How old (range from … to…)?
- Operation pressure (range from … to…)?

- Diameter (range from … to…)?
- Depth of cover (range from …to …)?
- Volume of CO_2 transported per annum?

c) Do CO_2 pipelines cross sensitive areas like densely populated areas or areas of environmental importance? Provide details.

d) If new pipelines are planned for CCS projects, explain how much of the above information do you have on them.

e) Is there a legal framework for the transport of CO_2 in pipelines? If yes, give details.

f) Are there any technical guidelines which have to be considered (or should be considered) when planning and operating a CO_2 pipeline? If yes, give details; in particular, is there any guidance/regulation concerning the level of impurities which may be present in the CO_2 in pipelines?

g) Which authorities are responsible for CO_2 transport [environment, health and safety, etc]?

h) Are CO_2 pipelines regulated, or have technical guidelines, separately from pipelines for other substances? If so please give specific details.

i) Are there any other regulations covering transport of CO_2 for CCS (Ship, Train or others)? If yes, give details.

j) Are CO_2 pipelines (particularly) considered in the Land Use Planning Policy?

k) Are areas where earthquakes are possible considered in guidelines/regulations? If yes, please give details.

3. CO_2 Injection Facilities

a) Is your country intending to inject CO_2 into strata:

- offshore?
- onshore?
- for Enhanced Oil Recovery (EOR)?

b) What (safety) regulations apply to the injection process?

c) Once the long term storage operation is completed and the site sealed off, do the safety authorities – or other authorities – have any involvement in long term monitoring of the site?

d) What methodology do you use or intend using for purposes of monitoring, reporting and verification of CO_2 captured and stored?

4. Emergency Planning

a) Has your country considered any emergency arrangements for a major incident involving CO_2?

b) Are there any specifications to be considered for CO_2 emergencies (measures, equipment, protection of rescue personnel etc.) compared with emergency planning for (other) dangerous substances?

5. (Major) Accidents

a) Are there any experiences with accidents involving CO_2 that happened in the past, whether in connection with CCS or other operations involving CO_2?

- How many accidents?
- Short description of the accidents/incidents (causes, consequences):

b) What lessons should be learned from these accidents / incidents?

c) What would you consider to be a critical quantity of CO_2 in terms of its capability of causing a major accident (e.g. 50t, 200t, 500t, 5000t? more? less?)?

6. Research

a) Are there any completed or ongoing research projects in your country on the safety problems of CO_2 for CCS, e.g. on: capture technology (for example what quantity of CO_2 is present at capture facilities); pipelines; human health/toxicity; concentration of impurities in the CO_2; materials used for pipelines/plants; and quantities of dangerous substances that could be present in conjunction with CO_2 capture facilities (e.g. H_2, O_2, CO, NH_3, methanol, H_2S)?

b) Does the research concentrate on any particular areas e.g. transport, storage, etc?

c) If yes to a) or b) above, give details:

7. Risk Assessment

Do you have any experience of risk assessment of CO_2 for CCS, for:

a) Pipelines?

b) Capture plant?

c) Injection facilities?

d) Storage?

If yes, please give details:

- Quantitative RA
- Qualitative RA

- Modelling of accident scenarios
- Others

Damage indicators:

- Human health
- Environment
- Others

Acceptance criteria:

- Short description of the methodology

8. (Risk) Communication

a) Is the public being informed about plans for new and/or the operation of existing CO_2 capture, transport and storage facilities? If yes, how?

b) Have any concerns been raised by the public or public organisations about the safety aspects of CCS projects? If yes, what has been your experience? What are the main concerns of people?

c) Is there any possibility for the public to participate in the decision making process regarding CCS projects? If yes, how?

- In what way are the remarks made by the public addressed by the competent authority? Does the competent authority react in any way on remarks made by the public? If yes, in what way?
- Do the official decision documents contain a chapter on communication with the public and/or remarks made by the public?

d) Lessons learned for other/future projects?

ANNEX 3

COMPILATION OF RESPONSES RECEIVED TO QUESTIONNAIRE

Preliminary Remarks	
Germany	The questionnaire is mostly not applicable to the situation in Germany, since the regulatory framework is just under development. This applies to most countries in Europe. The European Union directive on CO2 storage (2009/31/EG from April 23rd 2009) is to be implemented within a period of two years into national 'member state' law (by June 25th 2011). Until the EU directive is implemented in national law, a lot of questions in the questionnaire cannot be answered specifically. The CCS Directive amends several other Directives and one Regulation (EIA Directive, WFD, Directive on large combustion plants, Directive on environmental liability, Waste Framework Directive, IPPC Directive, Regulation on the shipment of waste). **Note: German experiences mentioned in the questionnaire are gained from research projects and pilot projects only.**
Switzerland	Having the project "Carbon Management in Power Generation" running (see http://www.carma.ethz.ch), Switzerland is interested in sharing experiences.
Turkey	As a matter of fact, Turkey does not have an activity for carbon capture and storage at the moment. There is a project coordinated by the Ministry of Energy and Natural Resources on this issue but it has not been finalized yet. Therefore, we couldn't fully complete the questionnaire. However, we want to indicate that: - CO_2 is currently transported in Turkey via pipelines by Turkish Petroleum Corporation (from Dodan region to West Raman Petroleum Field.), and also via tankers by private sector for marketing. - Turkey intends to inject CO_2 into strata for Enhanced Oil Recovery.

1. CO_2 Capture Facilities

a) Has your country identified sites for carbon capture ready generating stations, or are carbon capture facilities already operating?	
Belgium	No sites identified yet, nor facilities already operating.
Canada	At the moment, there are no carbon capture ready generating stations in Canada. There are five CCS demonstration projects which have all commenced: • the Alberta Carbon Trunk Line, in Alberta (the construction of the pipeline is scheduled to start in 2011 with completion of the first phase of the project planned for 2013); • the Shell Quest, in Alberta (the engineering and construction phase of the project started in 2010 and start-up is scheduled for 2015); • the Project Pioneer, in Alberta (on-site construction is scheduled to start in 2012 and the project is expected to be fully operational in 2015); • the Boundary Dam Integrated CCS Demonstration, in Saskatchewan (the project is scheduled to begin operating in 2015); and • the Swan Hills Synfuels In-Situ Coal Gasification and Sagitawah Power Generation, in Alberta (the project is scheduled to start operating in 2015). Three of these demonstration projects could qualify as identified sites for carbon capture ready generating stations: the Project Pioneer, the Boundary Dam Integrated CCS Demonstration and the Swan Hills Synfuels In-Situ Coal Gasification and Sagitawah Power Generation. The other two demonstration projects are not power generation projects. Worth mentioning, the IEA Weyburn-Midale CO_2 Monitoring and Storage Project (Saskatchewan) is a full scale research project which started in 2000 (the current phase is scheduled to end in 2011). This project is currently one of the largest CO_2 storage projects in the world and is included in the G8 list of CCS projects in operation. Finally, there are many other ongoing research and pilot projects on CCS in Canada. (Source: Alie and Kent)[14].
Czech Republic	Yes, several large combustion plants, especially power plants, have been found ready for CC(S). But none of them have been realized yet.
France	One site is operating in west-southern France and two sites have been identified for potential new facilities.

[14] Alie, C. and Kent, H., Canadian Carbon Capture and Storage (CCS) Demonstration Projects and Funding Sources. Last updated July 21, 2010. Environment Canada internal document.

Germany	Currently, there are research projects and pilot plants in Germany: In 2008, Vattenfall set up the world's first pilot plant for low-carbon coal-fired power plants at the *Schwarze Pumpe* site – an oxyfuel pilot plant with a thermal input of 30 MW. Planning is underway for a CCS demonstration facility at the site of the lignite-burning power station in Jänschwalde (new construction of an oxyfuel steam generator with a thermal output of around 650 MW_{th} and an electrical output of 250 MW). Plans also include retrofitting a steam generator with a post combustion capture installation (Source: Vattenfall Europe AG). Other research projects and pilot plants with post-combustion: – Pilot plant Niederaußem (RWE): capture of a CO_2 mass flow of 300 kg/h using activated methyl diethanolamine (aMDEA) – Pilot plant Staudinger: Capture of a a CO_2 mass flow of 40kg/h using a solution containing amino acid salts – Planned pilot plants in Wilhelmshaven, Heyden and at a third site. In their construction plans for new power plants applicants generally already consider the retrofitting with a CO_2 capture facility at a later time. In Schleswig-Holstein, for example, the general possibility of retrofitting CO_2 capture facilities at the site concerned will be reviewed in the course of the current approval procedures for coal-fired power plants under air quality control law, with a view to the expected future requirements of Article 36 of the IPPC Directive (as at 15th February 2010). The approval procedure for GKM Mannheim also took this issue into account, and imposed a condition that space must be reserved for the later construction of a CO_2 capture facility. In addition, the energy utility E.ON reports that all its newly built plants are certified as CCR by an independent body. This is on a completely voluntary basis as there is no official legal standard or requirement for carbon capture readiness (CCR) yet. E.ON has carbon capture facilities in operation but only for development and demonstration purposes. In terms of the availability of enough space for the capture technology Vattenfall says that the new plant in Hamburg-Moorburg is capture ready, the same at GKM Mannheim, New Block 8.
Korea	No stations yet. A few carbon capture facilities are being operated at bench-scale or lab-scale as follows. - Dry CO_2 capture plant (0.5 MW scale) in Hadong coal-fired power plant by Korea Institute of Energy Research (KIER) and Korea Electric Power Research Institute (KEPRI). - Ammonia CO_2 capture process by KIER, Hyundai Eng.
Netherlands	No specific sites for capture have been identified by the government. There is, however, a scientific capture facility in the Rotterdam area at the E. on electricity production site.

<table>
<tr><td>Norway</td><td>Two aquifiers are currently in used as sinks for CO_2 extracted from produced natural gas from the Sleipner field (Utsira) and Snøhvit (Tubåen). A test facility for carbon capture is currently being constructed at Mongstad (Test Center Mongstad – TCM). The goal of the TCM will be to offer an arena for purposeful development, testing and qualification of carbon capture technology. It will also aim to contribute to the international dissemination of the results of this work, so that the cost and risk of full-scale carbon capture plants can be reduced. The facility will have an annual capacity for capturing about 100,000 tonnes of carbon dioxide from flue gases. Feasibility studies are currently being performed for full scale CCS plants at the gas fired power plants at Kårstø and Mongstad.</td></tr>
<tr><td>Slovak Republic</td><td>Yes, but not operating at that time (major sources according to National Action Plan – power plants, refineries, steel plant etc.)</td></tr>
<tr><td>Sweden</td><td>We do not have any full scale Carbon Capture ready or operating facilities.</td></tr>
<tr><td>Switzerland</td><td>No</td></tr>
<tr><td>Turkey</td><td>Not applicable</td></tr>
<tr><td>United Kingdom</td><td>Yes. The sites to a certain extent have self selected, since they are focused on areas with fossil fuel combustion stations. The main clusters are in Scotland (for example, Longannet Power Station), the North East (e.g. Teesside), Yorkshire (the Hatfield site) Merseyside (Fiddlers Ferry), South Wales, Lincolnshire and the London area. The table below sets out details of known CCS projects.
<table>
<tr><th>Project and predicted start date</th><th>Type</th><th>What do we know about the Project</th></tr>
<tr><td>Longannet, Fife, Scotland

2014</td><td>Coal

4200MW capacity

Post combustion CO_2 capture of 2.5 million tonnes per year</td><td>Part of the DECC competition. Consortium comprising Scottish Power, National Grid and Shell

Owned by Scottish Power, and with Cockenzie, produces one third of Scotland's electricity</td></tr>
<tr><td>Cockenzie, East Lothian, Scotland

Not known</td><td>Coal but converting to gas

Post combustion CO_2 capture</td><td>Owned by Scottish Power

Will install a new HP gas pipeline and a short CO_2 pipeline which they hope to connect to the "hub" National Grid CO_2 pipeline servicing the Fife industrial location.</td></tr>
<tr><td>Hunterston, Ayrshire, Scotland

2016</td><td>New coal fired power station</td><td>Developer: Ayrshire Power Ltd

Will be Top Tier COMAH because of ammonia.</td></tr>
<tr><td>Powerfuel, Hatfield Park, Stainforth Doncaster</td><td>Phase 1 – Construction and operation of the natural gas combined cycle gas turbine and Phase 2 – Further</td><td>CCR condition attached as part of the S36 consent (just stipulates that land should be available for CCS plant).</td></tr>
</table>
</td></tr>
</table>

	2013	construction of the integrated coal gasification plant 900 MW capacity Pre-combustion CO_2 capture	Has applied for 180 million Euros funding for UK's first CCS project. Successful over rival schemes from E.ON at Kingsnorth, RWE at Tilbury and Scottish Power at Longannet. Regional Development Agency, Yorkshire Forward working in conjunction with Powerfuel, National Grid and Doncaster MBC.	
	Aberthaw, South Wales 2010	Coal 1500 MW	Developer RWE npower – will shortly submit a planning application for a carbon capture pilot project. Pilot plant will be 3MW in size	
	Doosan Babcock, Renfrew Scotland 2018	Oxyfuel	Demonstration carbon capture plant – 40 MW	
	Kingsnorth, Kent On hold	Post combustion CO_2 capture 2 million tonnes per year	Part of the DECC Competition although they have advised that they do not intend to proceed to build CCS demonstration plant at this stage. Subsea pipeline to the depleted Hewett gas field in the southern North sea	
	West Pennar, Pembrokeshire	Combined cycle generating station (CCGT) 2000 MW	RWE Npower Carbon capture condition attached to s36 consent	
	Kings Lynn, Norfolk	CCGT 1020 MW	Centrica Leasing Carbon capture condition attached.	
	Bridestones Developments, Carrington, Manchester	CCGT (extension from previous 380 MW s36 application) 860 MW	Carbon capture condition attached	
	Barking Power Station, Dagenham Essex	CCGT (extension from previous 470 MW section 36 application 1000 MW	Carbon capture condition attached	
	West Burton Power Station, Nottinghamshire	CCGT 1270 MW	Carbon capture condition attached EDF	
	Drakelow, South Derbyshire	CCGT 1220 MW	Carbon capture condition attached E.ON	

Severn Power Ltd, Uskmouth, Newport	CCGT 800 mw	Carbon capture condition attached
Centrica and Progressive Energy, Teesside 2013	Pre-combustion CO_2 capture, 5 million tonnes per year	
Scottish and Southern Energy, Ferrybridge, West Yorkshire 2015	Post combustion CO_2 capture 5 million tonnes per year	
Killingholme, West Yorkshire 2016	Precombustion CO_2 capture 2.5 million tonnes per year	Powergen and E.ON
Drymn Onllwyn, South Wales	Precombustion,1 or 2 million tonnes per year	Progressive Energy
Didcot, Oxfordshire RWE Npower	Pilot CO_2 removal of 1 tonne per day	Amine test rig
Spalding, Lincolnshire	Gas	

Further relevant information

Projects to be confirmed

Scunthorpe, Corus, post combustion

Three main ways to capture CO_2

Post combustion – CO_2 in the flue gases from burnt fuel is captured chemically by an amine or ammonia solvent.

Pre combustion – Gasified coal or natural gas is chemically split to form hydrogen and CO_2. The CO_2 is then separated for capture before combustion and the hydrogen is used as fuel.

Oxyfuel – the fuel is burnt in almost pure oxygen eliminating nitrogen from the combustion gases. The process produces CO_2 and large amounts of water vapour that needs removing before CO_2 capture can take place.

Scale terms for carbon capture plant

Pilot: 200 MWe
Demonstration: 300 MWe
Small full scale: 500 MWe
Large full scale: 1000 MWe

b) What current legislative measures currently apply to these installations?	
Belgium	Article 33 of Directive 2009/31/EC on the geological storage of carbon dioxide inserts a new article 9a in Directive 2001/80/EC on the limitation of emissions of certain pollutants into the air from large combustion plants. The new article 9a encompasses an obligation for all operators of combustion plants with a rated electrical output of 300 megawatts or more for which the original construction licence or, in the absence of such a procedure, the original operating licence is granted after 25 June 2009, to assess whether suitable CO_2 storage sites are available, CO_2 transport facilities are technically and economically feasible and it is technically and economically feasible to retrofit for CO_2 capture. If those conditions are met, suitable space on the installation site for the equipment necessary to capture and compress CO_2 is to be set aside by the operator.
Canada	There are currently no legislative measures in place concerning CCS installations specifically. However, since CCS projects are at least in part funded by the federal government, the requirement for a federal environmental assessment, as per the *Canadian Environmental Assessment Act*, may be triggered. At the provincial level, more legislative measures apply to CCS installations, although they are not again specific to these installations. In other words, no new legislative measures have been created specifically for CCS installations, and only already existing acts or regulations may apply to these installation.
Czech Republic	An act implementing the directive 2009/31/EC is under preparation.
France	A specific legislative frame has been designed to regulate these facilities.
Germany	Currently carbon capture facilities are subject to the permit of the retrofitted LCP (large combustion plant). The permit for the installation of carbon capture facilities comes under regulations of the "Bundesimmissionsschutzgesetz" (BImSchG, Nr. 1.1 der 4. BImSchV, 13. BImSchV, TA Luft 2002).
Korea	There are no legislative measures yet.
Netherlands	Environmental legislation comparable to other industrial installations.
Norway	The Petroleum legislation is covering the CO_2 capture from produced natural gas (Sleipner and Snøhvit). The Petroleum legislation is currently being amended to cover health and safety issues related to CCS with offshore storage sites. The ministry of petroleum and energy is currently working on a set of rules for the application process (for CCS storage facilities).
Slovak Republic	All common legislation in the field of environment, safety etc.

Sweden	The EU Directive 2009/31/EC is under implementation which will be ready in springtime 2011.
Switzerland	Not applicable.
Turkey	Not applicable
United Kingdom	Note: there are only pilot CCS projects in existence at the moment. No demonstration or full scale. The Health and Safety at Work etc Act 1974 and all associated legislation: Environmental Legislation Planning, consents and Licensing legislation.

c) What current technical standards currently apply to these installations?	
Belgium	--
Canada	There are currently no technical standards in place concerning CCS installations. However, on June 16, 2010, the Canadian Standards Association (CSA) and the International Performance Assessment Centre for Geologic Storage of Carbon Dioxide (IPAC-CO2 Research Inc.) announced a joint agreement to develop Canada's first CCS standard for the geologic storage of industrial emissions. The new standard will focus primarily on the long-term geologic storage of CO_2 deep underground, including site selection guidelines, monitoring and verification protocols, geological storage, operation and end-term stewardship, monitoring, modeling, and a verification program for projects, ensuring that the research program supports the development of general regulatory and legal frameworks for widespread development. It will provide essential guidelines for regulators, industry and others around the world involved with scientific and commercial CCS projects. (Source: CSA Standards).
Czech Republic	None related to CCS.
France	The technical standards are: • transportation of dangerous gases and liquids through pipelines standards • underground storages of natural gas standards
Germany	So far there are no technical standards established specifically for Carbon Capture technology. In particular there is no reference for Best Available Technology as state of the art. Technical standards and references will evolve with results and experiences from large scale demo installations. There are sets of rules which also apply to power plants with capture facilities (e.g. Federal Immission Control Act (BImschG), Article 1.1 of the Fourth Ordinance Implementing the Federal Immission Control Act (4th BImSchV), Thirteenth Ordinance Implementing the Federal Immission Control Act (13th BImSchV), Technical Instructions on Air Quality Control (TA Luft 2002), regulations on handling chemicals and pressure vessels). The main requirements for the new technologies, for example under air quality law, must be specified. In Germany, this is the task of the federal government.
Korea	There are no technical standards yet.
Netherlands	Installations are built using existing techniques and normal technical standards apply. Some parts may be built with a heavier type of construction (such as pipeline tunnels), but this is not required on the basis of the existing standards.
Norway	Relevant industry standards. Specific CCS norms/standards from DNV will become public in April 2010 for capture and transport.

Slovak Republic	All common technical standards.
Sweden	--
Switzerland	Not applicable.
Turkey	Not applicable
United Kingdom	British Standards would apply to the compression activity (for example, BS EN 13771-1:2003). There are many BS directly applicable to the storage of CO_2, but there are issues associated with scale and quantities that would be present at full scale CCS. Examples include BS EN 14620: Parts 1 – 4:2006.

d) Which authorities are responsible for these installations [environment, health and safety, etc.]?	
Belgium	The federal authorities are responsible for health and safety issues in these installations, the regions are responsible for environmental issues and environmental safety.
Canada	CO_2 storage implementation is expected to fall under the authority and responsibility of those agencies that regulate the energy industry (oil and gas, power generation), and would cover CO_2 capture, transportation (pipelines) and injection. However, groundwater protection falls under the authority of environment protection agencies. In this case, provincial agencies are expected to coordinate their activities to address the potential for leakage and environmental impact assessments. As an example, the Alberta Energy Resources Conservation Board (formerly the Alberta Utilities Board) has jurisdiction over CO_2 storage and coordinates with the Alberta Department of Environment concerning groundwater protection and with the National Energy Board (a federal agency) on trans-boundary issues. Existing federal and provincial oil and gas legislation covers certain aspects of CCS, including most capture and transportation-related issues, such as construction and health and safety issues. In most Canadian jurisdictions, CO_2 storage activities, in particular the definition of CO_2 storage, property rights (storage and access rights) and injection and post-injection activities (regulatory permitting, monitoring and liability) still remain to be addressed. (Source: IEA).
Czech Republic	The installation as a legal person is responsible for itself. There are many inspection authorities, inter alia The Czech Environmental Inspectorate,, Ministry of Environment, Ministry of Industry and Trade and its inspection bodies etc.
France	Environment and safety (same authority in France).
Germany	In Germany there is no particular legislation governing CCS. Current practice is that the responsible authorities for Carbon capture installations are the permitting authorities of the federal states (Bundesländer) within Germany. They are mainly responsible for environmental aspects but involve local authorities in issuing an integrated permit for the plant. Also involved is the responsible authority designated pursuant to the Directive on the European Emissions Trading System, in Germany this is the “Deutsche Emissionshandelsstelle beim Umweltbundesamt”.
Korea	Not clear yet. Ministry of Environment have a plan to amend related law.
Netherlands	The Ministry of Economic Affairs (mining permits), the Ministry of Housing, Spatial Planning and the Environment and the local and provincial authorities (permits for pipelines, environment, external safety, waste). The Ministry of Social Affairs and Employment (health and safety).

Norway	Ministry of labour and ministry of the environment.
Slovak Republic	Authorities in environmental field.
Sweden	--
Switzerland	Not applicable.
Turkey	Not applicable
United Kingdom	The Environment Agency and the Scottish Environment Protection Agency have responsibility for controlling discharges to atmosphere. The Health and Safety Executive have responsibility for ensuring health and safety at the site. If the site is subject to COMAH (the Seveso Directive), the COMAH legislation is enforced jointly with the EA/SEPA (the COMAH Competent Authority (CCA).

e) Do you think that there needs to be further legislation or technical standards to regulate the process of carbon capture, and possible storage of some CO_2 on site? If so, what is required?	
Belgium	This remains to be investigated.
Canada	No comment.
Czech Republic	A proper act is required, and under preparation.
France	Not in France, but there may be a potential for harmonization of different legislation on the European and possibly OECD scale.
Germany	To a large extent the core elements for regulating carbon capture and storage are specified in the CCS Directive. To be able to grant a permit to carbon capture facilities and reserve space for power plants to be accordingly retrofitted, the 4th and 13th Ordinances for implementing the Federal Immission Control Act (Bundes-Immissionsschutzgesetz, BImSchG), and the Act on the Assessment of Environmental Impacts (Gesetz über die Umweltverträglichkeitsprüfung, UVPG) must be amended. BAT for these new technologies (e.g. for restricting emissions) must be established. Special regulations for carbon storage are not envisaged within the German legislation for implementing the EU CCS Directive
Korea	Yes, legislative measures and technical standards to define the specification and standard of the process of CCS are required to apply CCS technology. For example, the quantitative measure of ability to capture CO_2, energy consumption grade of CO_2 capture process, and so on.
Netherlands	Yes. For example specifications with regard to materials, corrosion and improved estimates of acute toxic levels.
Norway	Further research with related development of technical norms and standards is needed.
Slovak Republic	Yes we do, the national law compilation regarding underground CO_2 storage will be finished to the end of June 2010.
Sweden	--
Switzerland	Not applicable.
Turkey	Not applicable

United Kingdom	Yes – both legislative and technical. <u>Legislation</u> 1. We believe CO_2 should be classified as a dangerous substance and be subject to COMAH (Seveso Directive) 2. We believe CO_2 in pipelines should be classified as a dangerous fluid. This would make pipelines carrying CO_2, major hazard pipelines and subject to the Pipelines Safety Regulations. HSE is currently consulting about this proposal. 3. We believe that the Health and Safety at Work etc Act should be extended to offshore activities (CO_2 sequestration), and we are currently considering whether our permissioning legislation should also apply. <u>Technical</u> There are many BS directly applicable to the storage of CO_2, but there are issues associated with scale and quantities that would be present at full scale CCS. There are no relevant standards.

f) Have you considered the implications of this activity for the land use planning policy? If so, give details	
Belgium	The new article 9a of Directive 2001/80/EC encompasses an obligation for all operators of combustion plants with a rated electrical output of 300 megawatts or more for which the original construction licence or, in the absence of such a procedure, the original operating licence is granted after 25 June 2009, *to set aside suitable space on the installation site* for the equipment necessary to capture and compress CO_2 if an assessment indicates that suitable CO_2 storage sites are available, CO_2 transport facilities are technically and economically feasible and it is technically and economically feasible to retrofit for CO_2 capture.
Canada	Land-use planning is mostly done at the provincial and municipal levels. The implications of CCS activity have most likely not been considered in terms of land-use planning at the federal level.
Czech Republic	Some comments and actions on the level of county, municipality (and even citizens) are possible.
France	General land use planning legislation around dangerous facilities in France requires such facilities to be included in the scope. There will be such a policy around the site shortly operated, based on risk assessment of the process. Since there was a land-use policy already set up in the area because of the former process of natural gas storage, there is no expectation, yet, that a big change would be experienced on this point
Germany	If establishments such as power plants are subject to the Seveso II Directive (96/82/EC), land use planning must take this into account for safety reasons, pursuant to Article 12, for the siting of new establishments, modifications to existing establishments and new developments in the vicinity of existing establishments (in Germany this applies to residential areas or other vulnerable areas pursuant to Article 50 sentence 1 of the Federal Immission Control Act). Power plants may currently be subject to the Seveso II Directive, for example, if ammonia is present. At the moment it is not know exactly if and in which amounts dangerous substances pursuant to Annex I of the Seveso II Directive (e.g. H_2, NH_3, methanol, H_2S, possibly degradation products of absorbents) may occur in the capture technologies. Additional information from E.ON: According to the provisions laid down in the European CCS Directive, E.ON takes into consideration the necessary space requirements for the plot of a future Carbon Capture retrofit for any planned power plant project as well as most projects currently under construction. E.ON does not see land use as a significant issue.

Korea	Not yet.
Netherlands	All activities with dangerous substances which lead to relevant risks have to be assessed according to the Dutch Decree on external safety for installations (Dutch abbreviation: BEVI). Implications for land use planning and emergency planning are part of this assessment).
Norway	Not yet, gas power plants in Norway close to sea and storage will be offshore. Norway has decided that carbon capture storage is only to take place offshore. There will be no such storages onshore in our country. Please note: At the time being there is no decision on the construction of a CCS installation in our country It is still on a preliminary planning level. Preparation and research have been carried out in order to clarify the current situation
Slovak Republic	Certainly CO_2 storage is deposition of dangerous waste disposal.
Sweden	--
Switzerland	No
Turkey	Not applicable
United Kingdom	Yes. Government guidance (Department for Energy and Climate Change – DECC) provided for fossil fuel combustion stations makes it clear that LUP issues must be taken into consideration. This is on the basis of guidance provided by HSE.

g) Have you considered the implications for emergency planning – if so, give details	
Belgium	Not yet.
Canada	The implications for emergency planning have not yet been considered.
Czech Republic	Guidance for emergency planning will be contained in the act.
France	A specific external emergency plan (based on Seveso-directive tools) will be put in place around the facilities. Again, since such an emergency plan had be designed formerly because of the storage of natural gas, no bug change is expected from this point of view.
Germany	So far not specifically for CCS.
Korea	Not yet.
Netherlands	See 1f)
Norway	Yes. Validation of release models for CO_2 is needed. Early detection and warning to the public is needed plus evacuation plans.
Slovak Republic	Of course, emergency planning will be involved into the new legislation.
Sweden	--
Switzerland	No
Turkey	Not applicable
United Kingdom	Yes, for pipelines. If the PSR are amended and the CO_2 pipelines become major hazard pipelines, emergency planning will have to be considered.

2. Transport of CO_2 for CCS purposes

a) Is CO_2 for CCS currently transported in your country? If so, by what mode, and how much CO_2 is transported per annum for each of the following options: Pipeline – Ship – Train – Others	
Belgium	**Pipeline – Ship – Train**: No **Others**: Road Transport (no data on the volume of CO_2 transported)
Canada	• **Pipeline**: Over 2.0 million tonnes of CO_2 per year are currently transported via pipeline at Weyburn-Midale. • **Ship**: CO_2 is not currently transported by ship. • **Train**: CO_2 is not currently transported by train. • **Others**: CO_2 is not currently transported by other means of transportation.
Czech Republic	**Pipeline – Ship – Train – Others**: No
France	**Pipeline**: Yes
Germany	So far CO_2 is not transported from CCS installations in Germany. Generally, transport of small amounts is possible in pressure vessels, tank lorries etc. For example, within the framework of the CO_2 Sink pilot project for underground CO_2 storage in Ketzin (Brandenburg) (also see 6. Research) around 30,000 tonnes CO_2 were transported with lorries (so far only food-grade CO_2). Up to now, transport of CO_2 through pipelines has only taken place over short distances within petrochemical installations.
Korea	No. There is not yet transportation of CO_2 in Korea.
Netherlands	No. Currently, there is no CO_2-transport for CCS (land storage). There is CO_2-transport through pipelines from the port of Rotterdam to greenhouses in the province of South-Holland. (so-called OCAP-pipeline).
Norway	**Pipeline**: 1Mtonnes/y at Snøhvit **Ship – Train**: Not applicable **Others**: 1Mtonnes/y at Sleipner, directly into aquifier via dedicated wellbore.
Slovak Republic	There is no CO_2 transport in Slovakia at that time.
Sweden	There are not yet transports of CO_2 for this purpose.
Switzerland	No

Turkey	CO_2 is currently transported in Turkey via pipelines by the Turkish Petroleum Corporation (from the Dodan region to the West Raman Petroleum Field), and also via tankers by private companies for marketing.
United Kingdom	**Pipeline**: No, but a number of CCS projects currently being developed using pipelines as the transport option. These projects are currently at conceptual design phase with some targeting operation by 2014/2015. **Ship/Train and others**: CO_2 for CCS is not currently transported within the UK. In the future, pipelines will probably be the preferred option with shipping a possibility. Transport by train is unlikely.

<table>
<tr><td colspan="2">

b) Concerning CO_2 pipelines, general facts:

- **How many pipelines?**
- **What length in total?**
- **How old (range from … to …)?**
- **Operation pressure (range from … to …)?**
- **Diameter (range from … to …)?**
- **Depth of cover (range from … to …)?**
- **Volume of CO_2 transported per annum?**

</td></tr>
<tr><td>Belgium</td><td>

How many pipelines? None

</td></tr>
<tr><td>Canada</td><td>

- **How many pipelines?** As mentioned above, one pipeline is currently in use at Weyburn-Midale.
- **What length in total?** The pipeline at Weyburn-Midale is 330 km long (North Dakota, USA to Saskatchewan, Canada).
- **How old (range from … to…)?** The pipeline construction at Weyburn-Midale was completed in 2000.
- **Operation pressure (range from … to…)?** The pipeline operating pressure at Weyburn-Midale is about 14 MPa (mega-pascals) or about 2000-2200 psi (pounds per square inch).
- **Diameter (range from … to…)?** No information currently available.
- **Depth of cover (range from …to …)?** No information currently available.
- **Volume of CO_2 transported per annum?** No information currently available

</td></tr>
<tr><td>Czech Republic</td><td>--</td></tr>
<tr><td>France</td><td>

Concerning CO_2 pipelines, general facts:

- **How many pipelines**: One at this time.
- **What length in total**: 29 kilometers
- **How old** (range from … to…): The pipeline was built 30 years ago for natural gas transportation
- **Operation pressure** (range from … to…): 30 bar
- **Diameter** (range from … to…): From 8”(inches) on the injection side to 12” (inches) on the capture side.
- **Depth of cover** (range from …to …): Most of the pipeline is underground (at least 1,40 meter deep)
- **Volume of CO_2 transported per annum**: Volume maximum = 60 000 t per annum

</td></tr>
</table>

Germany	So far there are no CO_2 pipelines for CCS installations.
Korea	No. There is not yet transportation of CO_2 in Korea.
Netherlands	See www.ocap.nl • **How many pipelines**: A network of pipelines. • **What length in total**: 97 km main pipelines and 130 km distribution pipelines • **How old** (range from … to…): The main pipeline is an old oil pipeline • **Operation pressure** (range from … to…): 8-22 bar • **Diameter** (range from … to…): Main transport pipeline 26 inches • **Depth of cover** (range from …to …): unknown • **Volume of CO_2 transported per annum**: On average 300000 t
Norway	• **How many pipelines**: One (Snøhvit – subsea pipeline). The planned CCS facilities related to the gas fired power plants at Kårstø and Mongstad will require subsea pipelines if realised. • **What length in total**: 120 km • **How old** (range from … to…): Installed 2005 • **Operation pressure** (range from … to…)? • **Diameter** (range from … to…): 8” • **Depth of cover** (range from …to …): Ca 1m • **Volume of CO_2 transported per annum**: 1 Mtonnes
Slovak Republic	--
Sweden	--
Switzerland	--
Turkey	Not applicable
United Kingdom	As above – none in operation as yet.

c) Do CO_2 pipelines cross sensitive areas like densely populated areas or areas of environmental importance? Provide details	
Belgium	There are currently no CO_2 pipelines in Belgium.
Canada	No information currently available.
Czech Republic	--
France	No densely populated area will be crossed by the pipeline. Some areas of environmental importance will be crossed but the pipeline is underground for almost the entire length.
Germany	So far there are no CO_2 pipelines for CCS installations.
Korea	No. There is not yet transportation of CO_2 in Korea.
Netherlands	Yes. The CO_2 pipeline crosses a number of built areas. There is no inventory available. There is a map on the OCAP website.
Norway	No
Slovak Republic	No comment.
Sweden	--
Switzerland	Not applicable.
Turkey	Not applicable
United Kingdom	Not known at this stage.

d) If new pipelines are planned for CCS projects, explain how much of the above information do you have on them	
Belgium	New CO_2 pipelines have not reached the planning stage yet
Canada	Four of the five CSS demonstration projects expect to transport CO_2 by pipeline. One of the demonstration projects, the Pioneer Project, will either transport the CO_2 by pipeline or the CO_2 will be injected into a saline aquifer near the plant. The pipelines for these demonstration projects will range between 60 and 240 km in length. These pipelines will transport between 1 and 1.6 million tonnes of CO_2 annually. (Source: Alie and Kent).
Czech Republic	There are no such plans so far.
France	A risk assessment would be necessary, including all relevant information (length, pressure, cover, mapping, potential for major hazard,…).
Germany	Pipeline from lignite-burning power station in Jänschwalde (also see 6. Research). Within the context of planning the CCS pilot plant at the site of the lignite-burning power station in Jänschwalde, two options for pipeline transport to possible storage sites will be reviewed (about 53km and 133km respectively). The capacity of both transport routes will be designed in line with the amounts of CO_2 coming from the pilot plant in Jänschwalde. In order to keep the impact on the environment and the population to a minimum, it is planned to follow existing natural gas pipelines as closely as possible [Vattenfall Europe AG]. For the planning for pipelines, however, the suitability of horizons for secure long-term storage must be proven through geological exploration.
Korea	Not yet planned.
Netherlands	New pipelines are planned for the CCS project “Barendrecht”. All of the above information is available.
Norway	No specific design data decided. Chemical composition of CO_2 to suit carbon steel pipeline.
Slovak Republic	No comment.
Sweden	--
Switzerland	Not applicable.
Turkey	Not applicable
United Kingdom	Only front end engineering design (FEED) details at present.

e) Is there a legal framework for the transport of CO_2 in pipelines? If yes, give details	
Belgium	There is currently no legal framework for the transport of CO_2 in pipelines yet. The Flemish Region will investigate whether such a legal framework is needed for its territory.
Canada	The *National Energy Board Act* has provisions for transport of oil and gas commodities across provincial and national boundaries. The federal *Transport of Dangerous Goods Act* has provisions for transport of hazardous waste across provincial and national boundaries. Provinces also have laws and regulations governing the movement of goods via pipeline within their jurisdictions.
Czech Republic	An act implementing the directive 2009/31/EC is under preparation.
France	Pipeline legislation (for transportation of dangerous gases and liquids) does include CO_2 transportation.
Germany	A regulation on CO_2 storage including pipeline transport is being prepared. In principle, transport of CO2 in pipelines can be regulated by a corresponding application of existing provisions – either those for energy supply lines under the Energy Industry Act (Energiewirtschaftsgesetz EnWG), or for pipelines under the Environmental Impact Assessment Act (UVPG). A preliminary examination procedure in accordance with the UVPG is required if the pipelines are larger than 150 mm (liquid) or 300 mm (gaseous) in diameter. If the preliminary examination finds that an EIA is necessary, a plan approval procedure would have to be carried out (Pipeline Ordinance – Rohrfernleitungsverordnung).
Korea	No. But there is a law for transportation of LNG in pipeline. Similar framework can be used.
Netherlands	Yes, much of this is laid down in the Mining Act. Pipelines also need to comply with the Dutch Decree on external safety for installations.
Norway	Yes if the ongoing update of the petroleum legislation is ratified. The coming norms/standards from DNV (public available after April 2010) will cover a number of aspects related to CCS.
Slovak Republic	No
Sweden	--

Switzerland	Not applicable for CCS purposes. However, all pipelines have to comply with pipeline laws and regulations: 746.1 Loi fédérale du 4 octobre 1963 sur les installations de transport par conduites de combustibles ou carburants liquides ou gazeux (Loi sur les installations de transport par conduites, LITC) (http://www.admin.ch/ch/f/rs/c746_1.html) 746.11 Ordonnance du 2 février 2000 sur les installations de transport par conduites (OITC) (http://www.admin.ch/ch/f/rs/c746_11.html) 746.12 Ordonnance du 4 avril 2007 concernant les prescriptions de sécurité pour les installations de transport par conduites (OSITC) (http://www.admin.ch/ch/f/rs/c746_12.html) 746.15 Géologie nationale 510.624 (http://www.admin.ch/ch/f/rs/c510_624.html) 746.17 Emoluments et taxes de surveillance 730.05 (http://www.admin.ch/ch/f/rs/c730_05.html).
Turkey	Not applicable
United Kingdom	No.

f) Are there any technical guidelines which have to be considered (or should be considered) when planning and operating a CO_2 pipeline? If yes, give details; in particular, is there any guidance/regulation concerning the level of impurities which may be present in the CO_2 in pipelines?	
Belgium	Guidance concerning the level of impurities which may be present in the CO_2 in pipelines is certainly relevant for Belgium, since a lot of the CO_2 captured will be coming from industry (cement, petrochemical industry, iron & steel, …) rather than from the power sector. CO_2 streams from industrial CCS applications tend to have significant higher levels of impurities than CO_2 streams from the power sector.
Canada	There are likely existing technical guidelines that affect CO_2 pipelines, but specific details are not available at the moment.
Czech Republic	An act implementing the directive 2009/31/EC is under preparation.
France	Usual technical document and standards (especially for surveillance and frequent inspection of the pipeline) apply in France. The CO_2 concentration is higher than 87%.
Germany	Technical guidelines for CO_2 pipelines are currently being discussed, but they have not been adopted yet. Technical rules for CO_2 pipelines could be based on inter alia the Technical Rules for Pipelines (TRFl) (apply to hazardous substances) or on the technical rules for natural gas and water (DVGW guidelines, e.g. G463, G466). Currently there are no guidelines concerning the degree of purity of CO_2 in pipelines. Required technical standards: - Standards for the technical design of pipelines (valves, sealing, welding seams,...) - Materials (Pipeline Standard PLUS requirements to cold resistance of steel, minimal crack growth at low temperatures, little embrittlement at low temperatures in case of leakages in CO_2 pipelines, ...) Monitoring (how and with which raster will the injection site be monitored?)
Korea	Not yet guideline.
Netherlands	Pipelines in the Netherlands need to comply with the Dutch industrial norm NEN 3650 and with the safety management system as laid down in the national technical agreement NTA 8000 and existing standards and policy guidelines for transport of dangerous substances (Dutch abbreviation: RNVGS).

<table>
<tr><td>Norway</td><td>We have seen different specifications for impurity levels.
Different proposed CO_2 specifications:
<table>
<tr><th>Com-pound</th><th>Specification (Kinder Morgan)</th><th>Specification (Ecofys)</th><th>Specification (Dynamis)</th></tr>
<tr><td>CO_2</td><td>Min. 95%</td><td>Min. 95%</td><td>Min 95,5 %</td></tr>
<tr><td>N_2</td><td>Max 4%</td><td>Max 4%</td><td>Max 4 % (combined all non cond. gases)</td></tr>
<tr><td>CH_4</td><td>Max 5 %</td><td>Max 4%</td><td>Max 4 % (Aquifer)
Max 2 % (EOR)</td></tr>
<tr><td>H_2O</td><td>257 ppm wt</td><td>Max 500 ppm</td><td>Max 500 ppm</td></tr>
<tr><td>O_2</td><td>10 ppm wt</td><td>Max 4 vol %</td><td>Max 4 %
(Aquifer, combined all non cond. gases)
Min 100 - 1000 ppm (EOR)</td></tr>
<tr><td>SOx</td><td>-</td><td>-</td><td>Max 100 ppm</td></tr>
<tr><td>NO</td><td>-</td><td>-</td><td>Max 100 ppm</td></tr>
<tr><td>H_2S</td><td>10-200 ppm</td><td>-</td><td>Max 200 ppm</td></tr>
<tr><td>H_2</td><td>-</td><td>Max 4 %</td><td>Max 4 % (combined all non cond. gases)</td></tr>
<tr><td>Ar</td><td>-</td><td>Max 4 %</td><td>Max 4 % (combined all non cond. gases)</td></tr>
<tr><td>CO</td><td>-</td><td>-</td><td>Max 2000 ppm</td></tr>
<tr><td>Glycol</td><td>Max $4*10^{-5}$ l/m^3</td><td>-</td><td>-</td></tr>
<tr><td>T °C</td><td>Max 50 ºC</td><td>Max 30 ºC</td><td></td></tr>
</table>
Quite a lot of research on corrosion effects ongoing and planned.</td></tr>
<tr><td>Slovak Republic</td><td>No</td></tr>
<tr><td>Sweden</td><td>--</td></tr>
<tr><td>Switzerland</td><td>Not applicable.</td></tr>
<tr><td>Turkey</td><td>Not applicable</td></tr>
<tr><td>United Kingdom</td><td>Technical standards for pipelines carrying CO_2 are not adequately developed to consider their MAH integrity requirements in design, routing, operation and maintenance. The effect of impurities is currently under evaluation but a detailed specification for pipeline operations that matches the requirements of appropriate standards yet to be developed, is not established</td></tr>
</table>

g) Which authorities are responsible for CO2 transport [environment, health and safety, etc]?	
Belgium	In Belgium, CO_2 transport is mainly a responsibility of the Regions (urban planning, environment and environmental safety, …). Public health and safety issues concerning CO_2 transport are a responsibility of the federal authorities.
Canada	Conventional thinking is that provinces are responsible for transport of CO_2 within their boundaries and the National Energy Board is responsible when CO_2 moves across provincial or national boundaries.
Czech Republic	Still under preparation.
France	Environment and safety (same authority in France).
Germany	In principle, the Länder are competent for issuing permits and monitoring pipelines. Depending on the legal basis, the environmental authorities would be responsible for procedures pursuant to the Act on the Assessment of Environmental Impacts (UPVG), and the authorities for economy – with the collaboration of the environmental authorities - for procedures pursuant to the Energy Industry Act (EnWG).
Korea	No authorities for CO_2 yet. Ministry of Knowledge Economy are responsible for transportation of gases including LPG.
Netherlands	The operator of the pipeline is responsible for the safe transport of CO_2. The authorities are responsible for permitting the construction and operation of a pipeline (Mining Act).Competent authorities are in general local government (municipalities and provinces). The Inspection of the Ministry of Housing, Spatial Planning and the Environment and the State Supervision of Mines are responsible for inspections and enforcement.
Norway	Ministry of labour and ministry of the environment.
Slovak Republic	No CO_2 transport, no competent authorities.
Sweden	--
Switzerland	Not applicable.
Turkey	Not applicable
United Kingdom	No pipelines currently in existence.

h) Are CO_2 pipelines regulated, or have technical guidelines, separately from pipelines for other substances? If so please give specific details	
Belgium	There are no regulatory frameworks from CO_2 pipelines yet. The pipeline transport of energy (natural gas) is a federal competence and regulated by the federal law of 12 April 1965.
Canada	There are currently no regulations or technical guidelines specific to CO_2 pipelines.
Czech Republic	An act implementing the directive 2009/31/EC is under preparation.
France	Not yet.
Germany	So far, there are no regulations on CO2 pipelines (see also answers 2e and d).
Korea	No
Netherlands	No
Norway	Subsea pipeline is the most likely scenario for CCS in Norway. Regulations for the petroleum activities can be applied with reference to relevant norms and new norms from DNV on CO_2 transport.
Slovak Republic	--
Sweden	--
Switzerland	None specifically for CCS purpose.
Turkey	Not applicable
United Kingdom	Safety and Integrity of pipelines (onshore and offshore) in UK are regulated under the Pipelines Safety Regulations 1996 (PSR). Specific additional duties exist under the regulations for pipelines carrying dangerous fluids. These duties require pipeline operators to notify HSE at key stages in the life cycle of a pipeline, prepare emergency procedures and a Major Accident Prevention Document which identifies hazards with of major accident potential; assesses and evaluates the risks arising from those hazards and ensures there is an adequate safety management system in place to manage the hazards. CO_2 is not currently considered as a dangerous fluid under PSR but plans are in place to change that. The process of change is currently under public consultation with plans to implement the changes in late 2010, if agreed. There are currently no separate technical guidelines for CO_2 pipelines in the UK but HSE is aware of and is supporting a number of separate Joint Industry Projects and associated research and development work in this area.

i) Are there any other regulations covering transport of CO_2 for CCS (Ship, Train or others)? If yes, give details	
Belgium	There are no other regulations covering transport of CO_2 for CCS.
Canada	There are likely other existing regulations that affect transport of CO_2 pipelines, but no specific details are available at this time.
Czech Republic	No.
France	Such a case has never occurred in France.
Germany	The international Transport of dangerous goods regulations apply. The following UN numbers are assigned to CO_2: 1013 if it is transported as compressed gas; 1845 if it is transported in solid form, dry ice; or 2187 if it is transported in a refrigerated, liquid form. RID/ADR/ADN (railway/road/inland navigation) contains a rule that UN 1845 is not subject to provisions. Maritime transport is only exempt if CO_2 is transported as a cooling agent in appropriate storage. In air transport CO_2 is always considered a dangerous good.
Korea	A law for high-pressurized gas and a law for city gas can be used. But now the main target of these laws is LPG.
Netherlands	General health and safety standards apply. No specific regulations for transport in framework of CCS.
Norway	No national regulation.
Slovak Republic	No
Sweden	--
Switzerland	None specifically for CCS purpose.
Turkey	Not applicable

United Kingdom	**Road**: The Carriage of Dangerous Goods and Use of Transportable Pressure Equipment Regulations 2009 (CDGUTPER) makes it an offence to carry dangerous goods by road other than in compliance with ADR. Carbon dioxide other than dry ice is regulated for road transport because ADR includes it in its list of dangerous goods. **Rail**: CDGUTPER applies. The International Carriage of Dangerous Goods by Rail (RID) enacts the European Directive on the inland transport of dangerous goods. **Sea**: The Dangerous Substances in Harbour Areas Regulations 1987 apply in harbours. Other legislation within UK territorial waters would be enforced by the Maritime Coastguards Agency.

j) Are CO_2 pipelines (particularly) considered in the land use planning policy?	
Belgium	New CO_2 pipelines have not reached the planning stage yet, they are not (particularly) considered in the Land Use Planning Policy.
Canada	Land use planning is mostly done at the provincial and municipal level, except when CO_2 moves across provincial or national boundaries. CO_2 pipelines have most likely not been considered in terms of land use planning at the federal level.
Czech Republic	No.
France	Such a case has never occurred in France. Yes, like any pipeline transporting dangerous gases or liquids.
Germany	No, up to now, land use planning has not given particular consideration to CO_2 pipelines. However, the amended Federal Regional Planning Act (ROG) lists CCS as an option for climate protection in its objectives. Transport pipelines have to be considered at the various stages of planning at Länder level (state development programme, regional land use planning). However, neither regional planning legislation nor pipeline legislation (which at present do not cover CO_2 pipelines, see above) go so far as to require, for example, a risk assessment in order to consider the option of a clearing distance because of possible hazards. Prior procedures for planning pipelines for CCS installations (see above): The locations of power plant and injection facility define the route of the pipeline. This results in a target range, in which technically feasible and economically viable route will be determined. Of course, natural and urban areas are taken into account while planning. There are a whole range of issues and principles to be included in the alignment, e.g. the consideration of ecologically valuable areas, the geological features of the planning area or a settlement area. Furthermore, the route has to be planned so that the effects on the transport pipeline are kept as low as possible.
Korea	No
Netherlands	According to the Decree on external safety for installations, all pipelines used for transport of dangerous substances, including CO_2, have to be implemented in local land use plans, from 2011.
Norway	Not very relevant for the currently planned CCS facilities in Norway, if carried out.
Slovak Republic	--
Sweden	--

Switzerland	None specifically for CCS purpose.
Turkey	Not applicable
United Kingdom	Yes, if the law is changed and CO_2 pipelines become major hazard pipelines, then consultation distances will be set around the pipelines, and LUP will be applied within these zones.

k) Are areas where earthquakes are possible considered in guidelines/regulations? If yes, please give details	
Belgium	No.
Canada	CO_2 will not be stored in areas where earthquakes are likely to occur.
Czech Republic	No.
France	Yes. Legislation defines areas concerned by seismic risk. In these areas, seismic risk has to be considered in the risk assessment of the pipeline, and standards and technical documents have to be applied.
Germany	So far, no specific regulations are in place concerning transport of CO_2. Furthermore, as yet there is no specific legislation for CCS in Germany. The core elements of the legal regulation are largely covered by the CCS Directive. Annex 1 of the EU Directive stipulates that the seismicity of a potential storage site must be investigated. The possible storage sites are mainly located in northern Germany. Risk of earthquakes in this region is so low that it can be disregarded. The storage potential identified in southern Germany extends across regions at risk for earthquakes (e.g. Saar-Nahe Basin and the Upper Rhine valley region Oberrheintalgraben). The feasibility of using the storage potential in these regions would have to be evaluated on a case-by-case basis.
Korea	No
Netherlands	Yes. The Dutch Mining Act does address land subsidence aspects caused by mining activities, e.g. in environmental impact assessments, subsidence assessments, monitoring plans and compensation regulations. Serious earthquakes have not occurred in the Netherlands and are considered extremely unlikely to happen.
Norway	Yes, shall be taken into design consideration.
Slovak Republic	--
Sweden	--
Switzerland	None specifically for CCS purpose.

Turkey	Not applicable
United Kingdom	The nature of the goal setting and risk based approach under the Pipeline Safety Regulations mean that it is the pipeline operators who have prime responsibility for reviewing relevant hazards with major accident potential and assessing the risks in terms of any threats to pipeline safety and integrity matters. Within this process they must demonstrate that all significant threats to pipeline safety and integrity have been adequately addressed. Where earthquakes are considered as a significant threat then they should be considered and assessed. However, it is considered unlikely that earthquakes will have a significant role in the UK.

3. CO_2 Injection Facilities

a) Is your country intending to inject CO_2 into strata: offshore – onshore – for enhanced oil recovery (EOR)?	
Belgium	**Offshore**: No (no suitable offshore geological formations available) **Onshore**: Yes (still profound geological research required) **Enhanced Oil Recovery (EOR)**: No (although Enhanced Coal Bed Methane Recovery projects are considered).
Canada	• **offshore?** A mapping project is currently in development to identify onshore and offshore geological storage potential in Canada. • **onshore?** A mapping project is currently in development to identify onshore and offshore geological storage potential in Canada. The provinces of Alberta and Saskatchewan are the most likely locations for future $C0_2$ capture and storage activities. • **Enhanced Oil Recovery (EOR)?** All CCS demonstration projects intend to inject CO_2 into strata for EOR, except one (Shell Quest – intends to inject CO_2 in a saline aquifer). Also, the CO_2 transported at Weyburn-Midale is used for EOR. Finally, the intent of most other CO_2 projects is to inject CO_2 for EOR.
Czech Republic	Onshore only. Both EOR and EGR are possible.
France	Offshore – Onshore – EOR: No
Germany	Currently, there is no CO_2 storage other than for research purposes in Germany. The industry has plans. However, no applications have been submitted up until now, and there is no legal basis yet. **Offshore:** There have been no specific applications. However, offshore storage does play a role in the industry's strategic planning. **Onshore**: In Germany there is currently one site operational where CO_2 is being injected onshore into a saline aquifer. This is the CO_2SINK project in Ketzin (Brandenburg), only for research purposes (see 6. Research). Two further sites are currently investigated for possible injection in the near future. This is the Altmark natural gas reservoir (project CLEAN, enhanced gas recovery), and the exploration work done by Vattenfall in Birkholz-Beeskow und Neutrebbin (Brandenburg) for the next two years in order to inject the CO_2 from the CCS-demo-project Jänschwalde. Owing to the low amounts of CO_2 stored, the results of Ketzin cannot be directly applied to future storage sites which are larger by a factor of 50 or 100. Furthermore, only food-grade CO_2 has been injected there so far (March 2010). **Enhanced Oil Recovery (EOR)**: There have been no specific applications.

Korea	**Offshore**: Yes, we have a plan to search for the offshore storage site for CO_2. Ullng basin and Pohang basin in the east sea are potential sites. **Onshore**: Yes, we have a plan to search for onshore storage site for CO_2 also. Kyungsang basin is a potential site. **Enhanced Oil Recovery (EOR)**: Yes, we are analyzing the feasibility of EOR for the gas field in the east sea.
Netherlands	Both offshore and onshore, possibly in some cases for EGR or EOR. **Offshore**: Gaz de France (North Sea.) **Onshore**: Barendrecht abandoned gas field (near Rotterdam).
Norway	**Offshore**: Yes **Onshore**: No **Enhanced Oil Recovery (EOR)**: Has been evaluated, but not implemented.
Slovak Republic	See response to 3 b)
Sweden	We have not yet identified and decided about any sites, but we are currently investigating suitable bedrocks or primary rocks. **Offshore**: ? **Onshore**; ? **for Enhanced Oil Recovery (EOR)**: No
Switzerland	So far, there are no public announcements regarding intent to inject CO_2 into the subsurface.
Turkey	Turkey intends to inject CO_2 into strata for Enhanced Oil Recovery (EOR).
United Kingdom	There are plans for demonstration projects for CO_2 storage offshore. We are not aware of any current plans for onshore storage or EOR use, although EOR is likely.

b) What (safety) regulations apply to the injection process?	
Belgium	The (safety) regulations of Directive 2009/31/EC on the geological storage of carbon dioxide will apply to the injection process.
Canada	Although not specific to CO_2, provincial regulations are in place for injection of material underground. CO_2 would be considered as an additional substance that is injected underground, and most likely covered by the same regulations. Also, the new standard developed by CSA and IPAC-CO2 Research Inc. mentioned in 1.c) will include both technical and safety guidelines.
Czech Republic	An act implementing the directive 2009/31/EC is under preparation.
France	Mining legislation and Seveso-like legislation.
Germany	As the EU Directive 2009/31/EC has not yet been transposed into national law, there are no specific rules governing technical safety for the injection process. The Ketzin project is the only case where CO_2 is currently being injected into the subsurface in Germany. This is a research project and is regulated by the mining authority (LBGR, i.e. Landesamt für Bergbau, Geologie und Rohstoffe Brandenburg). The regulatory process may not be representative for future CO_2 storage projects. However, a couple of documents have been issued and were approved: – a “Hauptbetriebsplan” (according to §§ 55 und 56 Bundesberggesetz [BBergG (mining law)]; – several “Sonderbetriebspläne” (for drilling, seismic investigations, monitoring, etc.); – for the injection process an “Alarm - und Gefahrenabwehrplan” was approved (according to §10 and Appendix IV, 12. BlmSchV) by the “Ordnungsamt des Landkreises Havelland”; – an “Eignungsnachweis”, which presents the case for injection and storage suitability. It is continuously updated and re-submitted for approval. The technical injection equipment is TÜV-Nord certified.
Korea	Not yet regulation.
Netherlands	Standard mining and Seveso Directive regulations.
Norway	Currently under development.
Slovak Republic	Regulations regarding CCS are being created in the process of the new law (onshore).

Sweden	--
Switzerland	None specifically for CCS purposes.
Turkey	Not applicable
United Kingdom	HSE is drafting proposed revisions to offshore legislation to bring CO_2 storage within our major hazard legislation (SCR, DCR, PFEER, MAR as well as HSWA). Structures used for the process would be classed as offshore installations and require safety cases.

c) Once the long term storage operation is completed and the site sealed off, do the safety authorities – or other authorities – have any involvement in long term monitoring of the site?	
Belgium	The regulations on the long term monitoring and stewardship of storage sites of Directive 2009/31/EC on the geological storage of carbon dioxide will apply.
Canada	Normal course of action is for the company to monitor the site until reclamation is complete. Once certified, the liability for monitoring is transferred from the last operator to the government. However, nothing specific for CO_2 has been developed. The province of Alberta is proposing to have something in place for the fall 2010.
Czech Republic	Yes, the state authority takes responsibility after min. 20 years.
France	Yes, there is an obligation for injection operator to monitor the site on the long term, under control of public authorities. Moreover, for the first project being operated in France, a public monitoring system will be put in place.
Germany	This is regulated in the CCS Directive which has been transposed into national law.
Korea	Yes, the plan for storing and searching for CO_2 storage site also include both closing and monitoring.
Netherlands	EU Directive 2009/31/EC on the geological storage of carbon dioxide applies, which means that all legal obligations relating to monitoring and corrective measures shall be transferred to the competent authority if the following conditions are met: (a) all available evidence indicates that the stored CO2 will be completely and permanently contained; (b) a minimum period – to be determined by the competent authority has elapsed – shall be no shorter than 20 years, unless the competent authority is convinced that the criterion referred to in point (a) is complied with before the end of that period; (c) certain financial obligations have been fulfilled; (d) the site has been sealed and the injection facilities have been removed. According to the directive, long term monitoring of sites after transfer of responsibility may be reduced to a level which allows for detection of leakages or significant irregularities. If any leakages or significant irregularities are detected, monitoring shall be intensified as required to assess the scale of the problem and effectiveness of corrective measures.
Norway	Regulation under development based upon the EU-Directive (Ministry of petroleum and energy).

Slovak Republic	Yes, they will have.
Sweden	--
Switzerland	Not applicable.
Turkey	Not applicable
United Kingdom	If there was no work activity at the site, HSE would not be involved.

d) What methodology do you use or intend using for purposes of monitoring, reporting and verification of CO_2 captured and stored?	
Belgium	The European Commission's guidance documents regarding the implementation of Directive 2009/31/EC on the geological storage of carbon dioxide are awaited to determine the methodology for the monitoring, reporting and verification of CO_2 captured and stored.
Canada	Some of the technologies being discussed for monitoring CO_2 movement are: • For seepage: aircraft, soil gas, in-situ tracers. • For leakage: 3-D seismic, tilt meter, pressure, in-situ tracers, logs, passive seismic. For migration: 3-D seismic, passive seismic, x-well seismic, tilt meter, pressure, injected tracers, in-situ tracers, logs, injection rates (Source: CCSTRM)
Czech Republic	We intend combining the methodology in the directive 2009/31/EC and in the act implementing the directive 2003/87/EC.
France	Quantity stored is monitored and reported on a quarterly basis. Monitoring is carried out in the injection device and in the storage underground.
Germany	This will be defined when the regulatory framework is in place, which is currently under development. The drawing up of monitoring concepts is specific to the site. There is no concept that can be applied to all sites. The project Stability of the Federal Institute for Geosciences and Natural Resources (BGR) is currently investigating the monitoring requirements and techniques. See also 6. CO_2SINK. The monitoring concept should take account of the following issues: • Monitoring the operation of the storage site, • Monitoring safety (also longterm safety), • Reporting obligations for emissions trading, • Public need for information. Different techniques are appropriate for the corresponding monitoring
Korea	Basically, sensors to monitor the concentration of CO_2 in ground and in the atmosphere can be used. Analysis of pH and ion concentration in the water in the ground can be used.

Netherlands	For each storage project a selection from all available monitoring techniques will be made based on the risk matrix of the project. Techniques can be selected with help of available tools such as the tool from the IEA (http://www.ieaghg.org Monitoring Selection Tool). This selection of tools will be compared with the monitoring program in the permit application and after discussion with the applicant a final selection will be prescribed in the permit. Each year a monitoring report will be submitted to the competent authority (CA). This report will be available to the public and contains the results of the monitoring program and an evaluation of that program. This evaluation can result in an update of the monitoring program (additional monitoring, less monitoring, different tools etc.). The report will be analysed and verified by advisors of the CA, any changes of the monitoring program will have to be approved by the CA. This methodology of program- measuring- analysing/reporting-program adjustment-measuring etc. will be used in each phase of a project (injection phase, pre abandonment phase, post abandonment phase) until transfer of liability. Monitoring, reporting and verification for compliance under the EU Emission Trading Scheme (EU ETS) will be done according to the Monitoring and Reporting Guidelines as set out by the European Commission. These ensure the effectiveness of the emission reduction of CCS projects that are linked to the EU ETS and contain methodologies for the monitoring of the entire CCS-chain: capture, transport and storage of CCS.
Norway	--
Slovak Republic	The methodology for stored CO_2 will be given in the new national law.
Sweden	--
Switzerland	Not applicable.
Turkey	Not applicable
United Kingdom	HSE would only be involved if there was work activity on site. If, for example, a well or borehole was maintained on site for data-gathering, we would have an interest in its operation and maintenance. Any seismic surveys from vessels would be MCA's responsibility. We would be interested in the well integrity as we are presently for an oil and gas production/ injection well and would want to see how the CCS operator monitored the well annuli to ensure that the well had integrity, *i.e.* monitoring for CO_2 but for leaks from the injection tubing to the annuli that surround it and from the injection "reservoir" into the annulus immediately adjacent to the injection tubing to ensure that any packer at the bottom of the well and above the reservoir still had integrity. If the question is about how the CO_2 storage would be metered similar to how oil and gas production is fiscally metered just now. HSE does not or I think will not get involved in this side of things.

4. Emergency Planning

a) Has your country considered any emergency arrangements for a major incident involving CO_2?	
Belgium	No.
Canada	There are currently no emergency arrangements in place concerning major incidents involving CO_2.
Czech Republic	Yes, an installation must have an emergency plan approved by a state authority.
France	No
Germany	There are no specific regulations for CO_2 (CCS) yet. CO_2 is not categorised as a hazardous substance or a substance relevant for major accidents (Major Accidents Ordinance) (clarification still necessary regarding purity/admixtures). Installations under mining inspection only have to draw up emergency plans for facilities subject to the 12th BImSchV (major accidents facilites). Underground mining of potash in the Werra mining district in Thuringia is a special case with regard to dangers in the context of CO_2 (also see answer to No. 5). For special incidents or accidents involving CO_2 there are special corporate regulations for activating emergency services based on the Allgemeine Bundesbergverordnung (ABBergV- Federal ordinance on mining) (emergency plan pursuant to Article 11 (1) (6) ABBergV).
Korea	We recognize the needs for emergency arrangements, but there is no specific plan yet.
Netherlands	Yes, but this does not lead to extra measures. Potential effects are expected smaller than those from existing activities.
Norway	These will be developed along with the possible implementation of CCS facilities.
Slovak Republic	This duty is expressed in the sound of the new law.
Sweden	No
Switzerland	No
Turkey	Not applicable
United Kingdom	If the changes to legislation outlined above take place, then emergency planning forms part of the regulatory requirement.

b) Are there any specifications to be considered for CO_2 emergencies (measures, equipment, protection of rescue personnel etc.) compared with emergency planning for (other) dangerous substances?	
Belgium	--
Canada	There are currently no considerations specific to CO_2 emergencies although the National Energy Board's *On-Shore Pipeline Regulations* require that there be emergency plans in place to cover spills and leaks. Such plans are to be prepared in accordance with the CSA's Z731 Emergency Preparedness and Response standard.
Czech Republic	No.
France	No
Germany	As CO_2 is odour- and colourless, it is noticed too late. Breathing in even CO_2 concentrations of around 8% upwards quickly leads to an incapacity to react and a subsequent unconsciousness. Therefore, most people are no longer able to leave the hazardous area by themselves, the MAC value (maximum allowable concentration) for CO_2 is 0.5 Vol%; breathing in air with approx. 5% upwards of CO_2 causes symptoms such as dizziness and drowsiness, approx. 8% upwards causes unconsciousness; according to the Federal Institute for Risk Assessment (Bundesinstitut für Risikobewertung, BfR), concentrations between 8% and 20% can be fatal within 30 to 60 minutes). Combustion systems may fail (for example cars for leaving the site of the accident, emergency vehicles, possibly helicopters). This must be considered when drawing up emergency plans. Possible accumulations of CO_2 at low points must be taken into account (sinks, pits, basements etc.). CO_2 occurs naturally in the potash mining district Werra in Thuringia. It is minerally bound in the salts of the Zechstein and occurs along joints or fault zones. During the 100-year mining history of the Werra potash district serious accidents involving CO_2 have occurred. Therefore there are specific corporate regulations for preventing CO_2-related accidents during the exploitation of potash in the Werra mining district. For underground operations they include: • Measuring of concentrations, monitoring gas, • Designation of underground safety areas, • Technological measures for extraction work, • Development of safety projects (guidelines for working in areas where CO_2 may pose a risk), • Personal safety gear, • Course of action requirements/ training.

Korea	Not yet specific plan.
Netherlands	No extra specifications.
Norway	Yes, HSE UK has issued some guideline for safe distances. But in general more research is needed to validate release model.
Slovak Republic	Yes, there are.
Sweden	--
Switzerland	Not applicable.
Turkey	Not applicable
United Kingdom	Cryogenic burns to rescue personnel and embrittlement of surrounding plant making it unsafe. The potential large scale of the release. Rapidly increasing consequences of exposure to CO_2; once above 7% a relatively small increase in concentration can result in an order of magnitude fatality probability. Escape issues at sea, where concentrations of CO_2 are likely to be greatest and may even prevent motorised escape. Detection equipment fails at below -40C. The dense nature of the CO_2; pits etc should be subject to confined entry procedures. Cryogenic effects may affect temporary refuge time.

5. (Major) Accidents

a) Are there any experiences with accidents involving CO_2 that happened in the past, whether in connection with CCS or other operations involving CO_2? • **How many accidents?** • **Short description of the accidents/incidents (causes, consequences)**	
Belgium	How many accidents: None
Canada	The Weyburn-Midale project has permanently been sequestering CO_2 since 2000 with no incidents.
Czech Republic	No.
France	Yes, but minor accidents. **How many accidents**: Three (not taking into account CO_2 emissions through chemical decomposition in case of fire in a chemical plants). **Short description of the accidents/incidents (causes, consequences)**: 1) Leakage on a pipeline of CO_2 in a Seveso chemical site. No casualty. 2) Two accidents in a big amusement/theme park with CO_2 storages (CO_2 used for producing fake smog) with breaking off or leakage of CO_2 bottles – First accident: two people intoxicated; second accident: four people intoxicated.
Germany	**How many accidents**: We do not know of any statistics for Germany. **Short description of the accidents/incidents (causes, consequences)**: In 2008 a CO_2 fire extinguishing system was duly activated by a fire in a factory building in Mönchengladbach, releasing around 40 t CO_2. As this area was not properly sealed off, a heavy gas cloud of CO_2 reached a sink at a time of no wind. This led to an unexpected exposure of emergency personnel. Combustion systems failed. 107 persons were affected (breathing difficulties, nausea), 19 of whom were hospitalised as a precaution. One person remained in hospital for more than 24 hours, due to being injured in a fall. In 2006 an open (and slightly iced) valve on a 10 kg CO_2 compressed gas cylinder in a small cellar, combined with a defective gas warning system, caused the deaths of two people. Another person sustained severe injuries and spent several days in intensive care. A danger sign on the opened trap door in the cellar warning about the accumulation of gas had been ignored. In the mines of the Werra potash district serious or even fatal accidents have occurred in connection with the CO_2 bound in the salts (see also point 4). CO_2 was released through the strike of a gas-impregnated rock zone or corresponding gas accumulations during mining (drilling and blasting). For this reason, potash mining in the Werra district has specific corporate regulations to prevent accidents with CO_2 occurring during extraction of potash salts.

	In 1908 there were heavy underground gas and salt blowouts in the Großherzog von Sachsen shaft mine near Dietlas. These led to CO_2 spreading to the surface via the mine workings and shafts and settling in the valleys. A similar accident occurred in 1953 in the Menzengraben mine mear Stadtlengsfeld. In wind-free conditions, 5 km of the valley filled with a gas mixture containing high concentrations of CO_2, jeopardising in particular the area of Menzengraben. The inhabitants took refuge with their livestock on a mountain. Some of the emergency vehicles were hindered from approaching the scene due to inadequate oxygen supply to the engines. This event cost the lives of three people (Duchrow 1997). Most recently, in 2008 at the Sünna potash mine, a worker died as a result of CO_2 poisoning. The victim had ignored a safety barrier. In addition, there are above ground gas blowouts at locations where basalt breaks through or at drilling sites (harvesting of CO_2 until 1994 through above-ground drilling). In 1911 there was a powerful eruption from a CO_2 drill hole which destroyed the building above the drill hole, fatally injuring the person inside (Duchrow 1997, "Der 100-jährige 'Rhönmarsch' in die Kohlensäurefelder des südthüringischen Kalibergbaus", in: Der Anschnitt, 49, 1997, No. 4 pp. 123 - 147).
Korea	**How many accidents**: No one with CCS, a few with other operations. **Short description of the accidents/incidents (causes, consequences)**: CO_2 for fire extinguishing in a museum was leaked in 2001. Sixty people were suffocated, and one baby died.
Netherlands	**How many accidents**: Leakage of a pipeline leading to a number of greenhouses 8 bar. **Short description of the accidents/incidents (causes, consequences)**: The leakage was caused by a bad weld that was discovered after several weeks. Accumulation in a culvert caused the death of some ducks.
Norway	Explosion in CO_2 pipeline (1998) – but it was caused by H_2 – and not relevant in this questionnaire.
Slovak Republic	No **How many accidents**: No accidents.
Sweden	No
Switzerland	No
Turkey	Not applicable
United Kingdom	There are many. HSL review attached as appendix.

Attachment to the UK response to Question 5a

Incidents related to carbon dioxide releases

(Report by Moonis, M. and Hare, J., HSL)

1. A delivery driver succumbed to carbon dioxide asphyxiation while dispensing CO2 from his tractor-trailer (1).

2. On 24th May, 1994 a plant operator was fatally injured when he opened a pressure vessel which was still under pressure in near supercritical fluid process, which employed methanol and carbon dioxide at pressure of 2000 psi. Apparently believing the vessel to be depressurised, the victim attempted to remove the heavy steel cover. The pressure was released, throwing the victim 10 feet across the room. The victim was transported to a hospital where he was pronounced dead later that night [(2)].

3. On 14th November, 1998 high-pressure gas containing carbon dioxide and hydrogen sulphide rushed out of an oil well near Nagylengyel, Zala county (SW Hungary). Because of the huge gas cloud, which developed above the well and was blown by the wind, about 2,500 people had to be evacuated [(3)].

   This is a case of geothermal resource being used in oil production. Natural gas, with a high content of CO_2 (~81 %) is produced, transported, and re-injected to form an artificial gas cap above the depleted part of the oil reservoir. The technology operates without compressors; compressor power is provided by the thermal lift between the production and the re-injection wells. The higher the extracted geothermal heat from the produced gas, the stronger the thermal lift and the higher the gas mass flow rate. In this case, the fluid carrying the geothermal energy is CO_2 gas (Bobok et al, 1998).

4. In Cerro Fortunoso field in south of Mendoza province, Spain, an incident occurred in the drilling of a well. After reaching bottom hole at depth of 1500 m and before the final interval had been cased, a high pressure CO_2 eruption began from casing at 1200 m. The gas began to flow up around casing already in place and eventually found two paths to surface through natural fissures in subsurface and produced two large craters 70 m south of the wellhead. Even with excellent planning and help of specialised companies, it took 30 days to drill a relief well and control the blow-out.

5. Dieng Volcano Complex, 1979, Indonesia, diffusive CO_2emissions occurred prior to major accident. 200,000 tonnes of pure CO_2 was released and flowed from volcano to plain below as a dense layer causing asphyxiation to 149 people. This incident was associated with a 'phreatic explosion', an explosion in which ground water is explosively evaporated by hot magma. CO_2 was released at the same time. It was considered the pure CO2 released must have accumulated in a shallow reservoir as high density fluid before the explosion and was then released through fractures as they opened up due to pressure build up in volcano prior to explosion (ex of leak from volcanic areas) [(4)].

6. Lake Monoun, Cameroon 1984, Lake Monoun overturned, causing sudden release of volcanic CO_2 leading to death of 37 people [(4)].

7. Lake Nyos, Cameroon 1986, 1.24 MT of CO_2 was released in few hours and asphyxiated 1700 people [(4)].

8. Yellowstone hydrothermal areas, USA diffuse degassing has been measured at about 16 MT CO_2 per year. In diffuse degassing, gaseous CO_2 can percolate to surface through porous zones on volcano flanks and through hydrothermal areas (4).

9. Horseshoe lake, Mammoth mountains California; 'treekill' was caused by CO_2 emerging through the ground along fault zones on the volcano's flanks, following a period of enhanced seismic activity. The enhanced concentrations of CO_2 in the soil killed a large number of trees (4).

10. Cava dei Sielci region, Alban Hills Volcanic Complex Italy, release resulted in deaths of more than 30 animals. This release too was associated with increased seismic activity in that area (ex of leak from volcanic areas) (4).

11. Paradox basin, Colorado plateau CO_2 seepage along faults results in CO_2 charged groundwater in several springs and through old well bores. A crystal geyser, now a tourist attraction, first erupted in 1935 when well being drilled, intersected a charged aquifer. The geyser erupts every 4-12 hours as result of pressure changes in the aquifer (ex of leak from sedimentary basin) (4).

12. Matradrecske, Hungary, ex of leakage as result of presence of permeable cap rocks above fields. High levels of have been recorded for sometime in this area. In 1992, residents in two houses in village suffered from headache and since then control flushing system have been installed (ex of leak from sedimentary basin) (4).

13. S&N groups Berkshire Brewery, a contractor's employee died having been overcome by release of CO_2in carbon dioxide recovery plant at Berkshire brewery. A detailed HSE investigation is currently underway. (http://www.scottish-newcastle.com/snplc/rsp/environment/incidents/)

14. **INCIDENTS INVOLVING** CO_2 **AS FIRE SUPPRESSANT**

    - Report presented by USEPA in 2000 searched various databases for CO_2-related incidents in fire scenarios. From 1975 till report was prepared, 51 cases of carbon dioxide incident records were located that reported a total of 72 deaths and 145 injuries resulting from accidents involving the discharge of carbon dioxide fire extinguishing systems.[12] All the deaths that were attributed to carbon dioxide were the result of asphyxiation(5).

    The Table 1 below presents a breakdown of CO_2 related incidents and deaths/injuries (5).

Table 1 Breakdown of CO_2 related incidents

Use Category		Number of Incidents	Deaths	Injuries
United States and Canada				
1975-Present	Military	9	10	15
	Nonmilitary	20	19	73
Before 1975	Military	3	11	0
	Nonmilitary	5	3	3
Total		37	43	91
International				
1975-Present	Military	1	4	5
	Nonmilitary	21	39	52
Before 1975	Military	0	0	0
	Nonmilitary[a]	3	33	4
Total		25	76	61
Total		**62**	**119**	**152**

[a] Included in the total international nonmilitary incidents, deaths, and injuries before 1975 are the 20 deaths resulting from the use of carbon dioxide as a fire suppressant in England from 1945 to the mid 1960s, for which the cause is unknown.

All the 13 military incidents were related to marine activities, compared to only 11 of 49 in civilian cases. Other civilian cases were from varied environments, airplanes, data processing centers, garages, mills, parking etc.

Different results show that accidental exposure to carbon dioxide during maintenance or testing was the largest cause. In some cases, non-compliance with safety procedures led to death/injury/exposure.

The reason was not solely asphyxiation in fire mitigating system atmosphere but comprised of different scenarios such as too much CO_2 released or escape of CO_2 to adjacent rooms during testing, accidental discharge or false alarm. The worst incident reported in this report is of an aircraft crash killing all 43 passengers onboard. The last transmission received indicated release of a CO_2 fire extinguisher in the forward cargo hold, minutes before the crash. However, it is not clear if any of the deaths can be attributed to CO_2 release **(this incident is from 1948)**.

15. Northumberland, 11th Feb 1995, a 60 year old man and his dog were asphyxiated when they sucked in CO_2. This was due to stythe or choke-damp released under unusual weather conditions when the low pressure outside caused venting of CO_2 from an abandoned coal mine [(6)].

16. A refrigeration repairman was overcome by dangerous levels of carbon dioxide from the evaporation of blocks of dry ice. The carbon dioxide released from the dry ice accumulated in a walk in freezer in a restaurant. (OSHA Region I News Release, 12.17.1999) [(6)]

17. OSHA News Release (July 31, 1996), the objective of this release was to present dangers of oxygen displacement by CO_2 in decorative waterfalls and mountains. The operator carrying out maintenance lost consciousness in this case. So did his partner in a rescue attempt. A security

guard and a passer-by tried rescue but had to give up when they too became dizzy. Adequate rescue was however provided by the fire department [(6)].

18. Canada, two men were asphyxiated when working in a water well 3 metres deep. A worker was trying to descale the screen at the well bottom using strong acid, which reacted with the carbonate deposits to release CO_2. The second man died while attempting to rescue the first [(6)].

19. Canada, a man entered a covered well that had not been used for 10 years. He became unconscious from lack of oxygen after descending 2 meters (7 feet). Fortunately, he was rescued and recovered fully [(6)]. (*This could be due to CO_2, H_2S or any gas.*)

20. Another fatal accident was at a Department of Energy experimental test reactor in Idaho on 28th July 1998. This involved an accidental release of carbon dioxide during routine maintenance that caused the one fatality and exposure to fifteen other workers. The incident occurred when de-energising electrical circuits for routine maintenance. As the last circuit breaker was opened, a sudden discharge from the CO_2 fire suppressant system occurred without a warning alarm for evacuation. Within seconds workers found themselves struggling in a lethal atmosphere with zero visibility. The investigation committee had concluded that the safety measures and procedures were not implemented and the incident could have been avoided had they been in place [(6)]. (http://www.id.doe.gov/foia/ineelaiintro.pdf)

21. A cross-country skier was found dead inside a large, mostly covered snow cave, one day after he was reported missing. The autopsy report suggested symptoms consistent with asphyxiation; carbon dioxide measurements inside the hole in which he was found reached 70 %. This area is known for having a high carbon dioxide flux attributed to degassing of a large body of magma (molten rock) 10 to 20 km beneath the ski area [(7)].

Some More Examples of Volcanic Origin CO_2 Discharges

22. *Nyiragongo, DR Congo,* erupted in 2002 and measured concentrations of CO_2 in some locations ranged from 20%-30% to 90 % above lethal concentrations and pockets of gas reached heights up to 40 metres. In years prior to the eruption, ground emissions of CO_2 in Goma and Lake Kivu were probably responsible for a number of fatalities [(8)].

Table 2 below summarises USA experience.

Table 2: Industrial experience in USA: 3100 km CO_2 pipelines (for enhanced oil recovery) with capacity of 45 Mt/yr[9]

Pipelines	Natural Gas Transmission (1986-2001)	Hazardous Liquids (1986-2001)	CO_2 (1990-2001)
No. of incidents	1287	3035	10
No. of fatalities	58	36	0
No of injuries	217	249	0
Property damage M$	285	764	0.469
Incidents/1000km/yr	0.17	0.82	0.32
Property damage/1000km/yr $	37,000	205,400	15200
Average Length of pipeline (back calculated)	505,000	240,000	2,800

References

(1). Potential Carbon Dioxide Asphyxiation Hazard When Filling Stationary Low Pressure CO_2 Supply Systems. (OSHA hazard info bulletin, June 5, 1996), http://www.osha.gov/dts/hib/hib_data/hib19960605.html

(2). http://www.cdc.gov/niosh/face/stateface/ma/94ma019.html

(3). Hungarian News Agency (MTI) (WHNA); 14 November 1998. Source: World Reporter (Trade Mark).

(4). IEA greenhouse Gas R&D Programme http://www.ieagreen.org.uk/glossies/naturalreleases.pdf

(5). Carbon Dioxide as a Fire Suppressant: examining the Risks, US EPA EPA430-R-00-002, Feb 2000. http://www.epa.gov/ozone/snap/fire/co2/co2report.pdf

(6). Case histories of carbon dioxide incidents. http://members.aol.com/hydratwo/co2.htm

(7). Hill, P.M., "Possible Asphyxiation From Carbon Dioxide of a Cross-Country Skier In Eastern California: A Deadly Volcanic Hazard", Wilderness And Environmental Medicine: Vol. 11, No. 3, Pp. 192–195

(8). Baxter, P.J. and Ancia, A., 2002. Human health and vulnerability in the Nyiragongo volcano crisis Democratic Republic of Congo 2002: Final Report to the World Health Organisation, World Health Organisation

(9). Race, J., "designing safe CO_2 transport structure for UK", presentation at Newcastle University school of marine science and technology, viewed at: http://www.energyinst.org.uk/content/files/newcastleresearch.pdf on 21st Apr 2007

b) What lessons should be learned from these accidents/incidents?	
Belgium	Not applicable.
Canada	N/A
Czech Republic	--
France	Leakage leading to toxic cloud is the most important problem to fear and tackle regarding CO_2 CCS.
Germany	Risk management and mitigation plans have to take experiences from accidents into account. Today, the occurrence of CO_2 during mining in the Werra potash mining district is controlled through technological and organisational measures. In Thuringia, present-day underground potash mining in working areas where CO_2 may occur is carried out based on special operational plans. Measures to prevent sudden uncontrolled gas blowouts or accumulations include first and foremost a mining technology taking account of the risks, combined with the use of gas detectors and sufficient blowing in of fresh air. Furthermore, mining personnel are comprehensively trained and made aware of the risks of CO_2. The mine rescue brigade, the emergency personnel, is equipped for any scenario.
Korea	Leaked high-concentrated CO_2 can damage people significantly.
Netherlands	Intensify inspections for smaller sized pipelines and improve integrity of these pipelines.
Norway	CO_2 is a substance that can be lethal when released.
Slovak Republic	--
Sweden	--
Switzerland	Not applicable.
Turkey	--
United Kingdom	Hazards from CO_2 should not be underestimated. It is not just a simple asphyxiant – it has more toxicity than that. Primary containment standards are very important (and need to be developed for CCS processes). As it is heavier than air, CO_2 will tend to accumulate in depressions etc. This should inform emergency response planning. Pits etc should be subject to confined entry procedures.

c) What would you consider to be a critical quantity of CO_2 in terms of its capability of causing a major accident (e.g. 50t, 200t, 500t, 5000t? more? less?)?	
Belgium	--
Canada	A critical quantity for CO_2 has not yet been determined.
Czech Republic	It depends on the weather, temperature, shape of the landscape or other characteristics of area...
France	Depending on storage conditions. No threshold has been set in the French legislation.
Germany	It is the concentration of CO_2 that is important if a leakage occurs. This depends on the dispersion. If CO_2 is released into the normal atmosphere from a high-pressure (> approx. 80 bar) vessel, it forms dry ice and drops to the ground. Thus, it is only transported over short distances, and it is visible. If gas is released into a permanently closed area, or if this area is low, it creates a life-threatening situation and just a few tonnes can pose a danger. In an open space, the seriousness of the risk depends on wind, temperature (thermal lift) and the topography of the environment. A critical amount of CO_2 which might lead to a serious accident cannot be derived for the conditions at the underground mine in the Werra potash mining district in Thuringia. It rather depends on the geological conditions (gas impregnation/ accumulation) and the mining situation. In underground mining even an amount of less than 50 tonnes of CO_2 may cause a serious accident. A research project by the Federal Environment Agency (to be concluded in summer 2010) will study accident and major accident scenarios for storage processes and their possible impacts. It is possible that this project may provide information on the corresponding critical amounts.
Korea	I personally think that speed and concentration are more important than the amount of CO_2.
Netherlands	[Question from the Netherlands: what is considered as a major accident?] Depends on circumstances. The size of an accident depends (amongst others) on the way the release takes place. For example a release of CO_2 of less than 50 t can be critical in a case where CO_2 does not disperse due to lack of velocity. Incidents with CO_2 fire extinguishing systems in large warehouses in Germany illustrate this.
Norway	Impossible to answer without knowing more about volume/location/weather conditions that can be occupied by CO_2.

<table>
<tr><td>Slovak Republic</td><td>It is impossible to distinguish it according to above mentioned thresholds; each locality can be different and main factors are: relief of the terrain, weather and diffusion condition, amount of CO_2 per time unit, density of settlements, etc.</td></tr>
<tr><td>Sweden</td><td>--</td></tr>
<tr><td>Switzerland</td><td>No numerical value provides a suitable indicator for a critical quantity of causing a major accident.

Applying a Hazards Effect Management Process (HEMP) in the parlance of Health, Safety and Environmental (HSE) Management Systems and, on an as needed basis, the development of an HSE Case will reveal whether or not quantities of CO_2 released may contribute to a major accident. A list of threats (e.g. enclosed cellar space where CO_2 may accumulate) needs to be composed along with controls in place to provide effective barriers. The integrity of each barrier needs to be assured in order to minimize the risk of the top event (major accident) taking place.

Consequences of the major accident need to be minimized by having in place recovery preparedness measures that do not escalate the consequences of the major accident. It is quite easy to speculate on a major accident with a perceived low quantity of CO_2 being released and it is easier still to imagine no major accident with millions of tonnes of CO_2 being released. We advocate that applying a single numerical value is not a suitable approach to manage the risk of a major accident to a level commensurate with for example the ALARP principle (as low as reasonably practicable).</td></tr>
<tr><td>Turkey</td><td>--</td></tr>
<tr><td>United Kingdom</td><td>Early work in the UK, suggests a figure around 50 tonnes.</td></tr>
</table>

6. Research

a) Are there any completed or ongoing research projects in your country on the safety problems of CO_2 for CCS, e.g. on: capture technology (for example what quantity of CO_2 is present at capture facilities); pipelines; human health/toxicity; concentration of impurities in the CO_2; materials used for pipelines/plants; and quantities of dangerous substances that could be present in conjunction with CO_2 capture facilities (e.g. H_2, O_2, CO, NH_3, methanol, H_2S)?	
Belgium	Belgium has one federal scientific project (2006-2011) on CCS. It mainly deals with capture technology, geological studies in order to assess possible storage reservoirs and transport of CO_2. A small part analyses the potential risks and safety problems that could occur with CCS, mainly regarding the storage aspects.
Canada	Yes. Please see details in c).
Czech Republic	There is a completed project on the potential of CCS technology in the Czech Republic, particularly from the geological point of view. It concludes that the total storage capacity is more than three Gt of CO_2.
France	Yes
Germany	There are a range of research and development projects on CCS in Germany. Relevant projects that we are aware of include: *Projects under the Environmental Research Plan (UFOPLAN) – Projects of the Federal Environment Agency, area of competence of the Federal Environment Ministry* 1) Stand der Technik von Kraftwerken mit CO_2-Abscheidung (BAT for power plants with CO_2 capture facilities) (concluded November 2009). Presentation of technologies and thus determination of related environmental impacts (e.g. emissions into atmosphere, into water, residues), information on captured CO2 stream, proposal for measuring programme. Description of German, European and international activities (existing and planned pilot installations, research and development projects in science and industry). 2) Sicherheit und Umweltverträglichkeit der CO_2-Speicherung (Safety and environmental performance of CO_2 storage), part 1 Speicherprozesse (storage processes), part 2 Risikoanalyse und systematische Risikominimierung (risk analysis and systematic minimisation of risks) (approximately until summer 2010). The work packages include: Storage characterisation, identification and assessment of risks in processes, determination of protected assets, prevention and removal of damages (scenarios for (major) accidents and potential impacts, derivation of evaluation criteria, requirements for emergency plans, proposals for lists of measures), methodology for systematic risk analysis and management. GEOTECHNOLOGIEN (geotechnologies) is a geoscience research and development programme supported by the Federal Ministry of Education and Research and the German Research Foundation (DFG), including *Technologies for a safe and longterm storage of GHG CO_2*. An overview of ongoing research work in Germany is shown here:

	http://www.geotechnologien.de/portal/cms/Geotechnologien/Forschung/Laufende/CO2-Speicherung+II/ For example: *COSONOStRA* (on CO_2 pollution of storage sites) *CO_2-SO_2-NO_x-Stimulated Rock Alteration* – This interdisciplinary project studies the processes and interactions of industrially captured CO_2 in potential storage and cap rock. http://www.geotechnologien.de/portal/cms/Geotechnologien/Forschung/Laufende/CO2-Speicherung+II/COSONOStRA http://www.geotechnologien.de/portal/cms/Geotechnologien/Forschung/Beendete/CO2-Speicherung+I For example: *CO_2-UGS-RISK* – Assessment of the Long-Term Risk and Sustainability of Underground Storage of CO_2 in Germany Current Practises The Reactor Safety Association (GRS) in Braunschweig is preparing a comprehensive assessment of long-term risk and sustainability of various CO_2 storage options based on existing data and data which will be collected within the framework of the projects. http://www.geotechnologien.de/portal/cms/Geotechnologien/Forschung/Beendete/CO2-Speicherung+I/CO2-UGS-RISK *CO_2SINK* – The EU research collaboration project CO_2SINK is concerned with CO2 storage in a deep saline aquifer onshore near the city of Ketzin. The aim of the project is to improve the understanding of scientific and practical processes which are related to underground CO_2 storage. The project was approved based on the Federal Mining Act. From the start of injection on 30 June 2008 until 7 March 2010, 31,482 tonnes of CO_2 were injected. The project will be concluded on 31 March 2010. [GFZ German Research Centre for Geosciences] Only pure (food-grade) CO_2 is injected in Ketzin. CO_2SINK also focuses on the development and review of monitoring processes. Follow-up projects have been applied for at the same site. http://www.co2sink.org *COORAL* – The collaborative project COORAL (CO_2 purity for capture and storage) aims to determine the concentrations of gas pollution which are admissible for CO_2 capture facilities and underground storage and to present the options for influencing them through the operation of the power plant and the CO_2 capture and treatment processes. Another objective of the project is to ensure safety during transport and injection. Types of steel and compressor technologies are being studied as well. http://www.tu-harburg.de/iet/forschungsprojekte/cooral.html http://www.bgr.bund.de/cln_109/nn_1634034/EN/Themen/Geotechnik/CO2-Speicherung/COORAL/English/english__node.html?__nnn=true *COORETEC* is an initiative of the Federal Ministry of Economics and Technology (BMWi) for the support of research and development of power plants that use fossil fuels and are viable for the future. COORETEC stands for CO_2 Reduction Technologies. It pursues the strategies of a) efficient conversion of fossil fuels in power plants and b) CO2 capture and transport with the objective of a longterm safe storage in

	geological formations. http://www.cooretec.de/ Several research projects within the framework of federal programmes (BMWi, BMBF) were concerned with the oxyfuel capture process, including a pilot plant at the Brandenburg University of Technology in Cottbus. A three-year testing programme is currently being carried out at the oxyfuel pilot plant Schwarze Pumpe. *Projects of the Federal Institute for Geosciences and Natural Resources (BGR)* http://www.bgr.bund.de/cln_109/nn_329330/DE/Themen/Geotechnik/CO2-Speicherung/Projekte/projekte__node.html?__nnn=true (also available in English) *Industry* E.ON reports that there is a big amount of research projects concerning CCS and in some cases they are regarding such issues (not all were prepared within Germany or Europe), partly prepared by external parties. Moreover from operation of pilot plants E.ON has experience with impurities in the CO_2 stream. Transport: - Dense CO_2 release modelling validation data - Fracture arrest (stopping spread of fractures by selecting the right materials) - Corrosion - Effect of contaminants on the phase diagram - Material compatibility - Water solubility and hydrate formation
Korea	Not yet.
Netherlands	Yes. CO_2 acute toxic levels studies & modelling for pipelines.(Ongoing research). Please also refer to http://co2-cato-nl/cato-2/program-overview for more information on the Dutch CCS research program (CATO-2).
Norway	Yes DNV JIP CO_2 Pipetrans Phase 2, Several research projects supported by Forskningsrådet and Gassnova, Capture Pilot plant at Mongstad, Statoil research, Aker Clean Carbon for capture and more.
Slovak Republic	No information.
Sweden	No
Switzerland	Yes.
Turkey	A project on feasibility study of CCS in Turkey has been finalised and project results show that although there are available sites identified, under current costs CCS application in Turkey is far from being feasible in the country[15]. No risk assessment studies have been carried out.
United Kingdom	Yes there are several in the UK and the EU/worldwide originated in the UK.

[15] At the time of the analysis the feasibility study of CCS in Turkey was still underway.

	HSE is of the opinion that its established toxic load values and dose time relationship are adequate for the assessment of CO hazard exposure

b) Does the research concentrate on any particular areas e.g. transport, storage, etc.?	
Belgium	One topic that receives more than average attention is the cross-border issue of transport and storage of CO_2, especially the interaction between Belgium and The Netherlands. The project is further multi-disciplinary, and deals with capture technology (technology outlooks in relation to cost and performance), geological studies (in order to assess possible storage reservoirs) and transport of CO_2 (pipeline infrastructure with cost estimations and infrastructural planning). These data are used for making integral techno-economic simulations on CCS in Belgium.
Canada	Yes. Please see details in c).
Czech Republic	--
France	Yes
Germany	see response to 6a.
Korea	--
Netherlands	Pipelines
Norway	They cover a number of relevant aspects of CCS.
Slovak Republic	Some research is concentrated predominantly on the storage sites assessment.
Sweden	--
Switzerland	Yes.
Turkey	--
United Kingdom	Transportation is a key area as this is where most uncertainty, risk and needs for standards exist. Considering the enormity of the scale of operations significant research effort is also being applied to capture and full process control. Intermediate semi-cryogenic storage may also be required for shipping or process stabilisation and as such research in to the hazards and so on for such operations is also under development.

c) If yes to a) and b) above, give details	
Belgium	More details can be found in the report of the first phase of the project: i) on the project website http://www.pss-ccs.be// or ii) on the programme website: http://www.belspo.be/belspo/ssd/ The project coordinator can be contacted for further information: Kris Piessens - Kris.Piessens@naturalsciences.be – 0032 (0)2 788 76 34, or the funding organisation Belspo: Sophie.Verheyden@belspo.be – 0032 (0)2 238 36 12.
Canada	As mentioned in Section 1, there are several ongoing research projects on CCS in Canada, many of which include a research component on safety problems related to CO_2. For example, commissioned in 1995, the CanmetENERGY's CO_2 Research and Development Consortium (program under Natural Resources Canada) was the world's first advanced oxy-fuel combustion pilot-scale research facility. The research program's objective is to help bring oxy-fuel combustion, advanced power cycles, integrated multi-pollutant, and CO_2 capture technologies to a level of commercial acceptance. The Consortium is now in phase 9, which is developing the first-of-its-kind CO_2 capture and compression unit. This unit will be capable of separating and compressing CO_2 from combustion flue gas streams for pipeline transportation. Part of this work involves studying CO_2 phase change and the impact of impurities in the gas stream on the process. This has important practical applications relating to the CO_2 pipeline, material selection, and commercial design and implementation of these systems. Other on-going R&D activities include the modelling of advanced near-zero emissions cycles, including supercritical and ultra supercritical oxy-coal plants with CO_2 capture, the development and testing of multi-pollutant control strategies, as well as the testing and optimization of a novel multi-function oxy-fuel/steam burner. (Source: CanmetENERGY).
Czech Republic	--
France	Most of the research is being carried out on safety and integrity of the storage underground (monitoring and stability over centuries, leaks around the injection wells).
Germany	<u>Answer to (a) and (b)</u>: Some utilities like E.ON, Vattenfall and RWE have also CCS-projects in other countries: plenty of research projects funded partly by industry are looking at all relevant aspects of CO_2 storage – besides capture and transport. This involves technical issues like site characterization, forecast numerical modeling, monitoring and risk assessment. Chemical interaction between CO_2 together with other flue gas species or with different natural or artificial media is being investigated as well. For storage integrity during operation methodologies in geomechanics are being further developed starting from the experience in underground gas storage. E.ON in general addresses the technical aspects of the process chain, abandonment, monitoring, license application, communication and the legal framework (www.eon.com/ccs).

Korea	--
Netherlands	So far, a temporary acute toxic level function is used, following a conservative approach. Supercritical aspects are as yet unknown. Research is to be carried out on these aspects.
Norway	--
Slovak Republic	The National project regarding CO_2 suitable storage sites selection is ongoing.
Sweden	--
Switzerland	The hazards associated with CO_2 need to be managed in order to prohibit a hazard becoming a "safety problem" (the question posed in 6a is rather misleading). The Swiss Federal Office of Energy, the Board of the Swiss Federal Institutes of Technology and a group of regional utility companies fund the Swiss CARMA Project (Carbon Management in Power Generation; http://www.carma.ethz.ch/index). CARMA aims to explore the potential and feasibility of CCS systems deployment in Switzerland, within the framework of future energy scenarios. Moreover, it aims to exploit available expertise to develop new CCS technologies and know-how that might be applied in Switzerland and worldwide. The project approaches CCS technologies from multiple perspectives: research will focus on the technical, environmental, economical, societal and legal issues related to them. A number of topics cover issues (not problems) related to CO_2 for CCS. For example a topic that is addressed by CARMA covers the possible consequences of CO_2 injection into the deep subsurface on natural, triggered and induced seismicity (SP 3: Assessment of geological storage potential in Switzerland).
Turkey	--
United Kingdom	--

7. Risk Assessment

Do you have any experience of risk assessment of CO_2 for CCS, for: a) Pipelines? – b) Capture plant? – c) Injection facilities? – d) Storage? **If yes, please give details: Quantitative RA – Qualitative RA – Modelling of accident scenarios – Others** **Damage indicators: Human health – Environment – Others** **Acceptance criteria: Short description of the methodology**	
Belgium	Do you have any experience of risk assessment of CO_2 for CCS, for: a) **Pipelines**: No b) **Capture plant**: No c) **Injection facilities**: No d) **Storage**: See answer 6 a)
Canada	Integrated evaluative models and tools for risk assessment are not currently available. (Source: CCSTRM) At the moment, only a couple of modelled scenarios are being studied to evaluate the impact of an accidental CO_2 leak. **Do you have any experience of risk assessment of CO_2 for CCS, for:** **a) Pipelines?** No **b) Capture plant?** No **c) Injection facilities?** No **d) Storage?** No
Czech Republic	No.
France	**Do you have any experience of risk assessment of CO_2 for CCS, for:** a) **Pipelines**: yes b) **Capture plant**: ongoing c) **Injection facilities**: yes d) **Storage**: ongoing • **Quantitative RA**: ongoing • **Qualitative RA**: no • **Modelling of accident scenarios**: Yes (pipeline, capture, injection facilities)/ ongoing (storage) **Damage indicators:** • **Human health**: same as Seveso sites • **Environment**: same as Seveso sites **Acceptance criteria – Short description of the methodology**: Risk assessment and comparison with acceptability criteria.

Germany	a) **Pipelines**: As there are no projects, we can report no experience gained with risk assessment of CO_2 pipelines. b) **Capture plant**: E.ON Ruhrgas, a company of the energy industry, has informed that together with the supplier E.ON prepared a risk assessment for one of their pilot plants. Furthermore, a Hazard identification was prepared for a Capture Plant. Hazard and operability studies are planned for projects in the future. c) **Injection facilities**: The Federal Institute for Materials Research and Testing (BAM) estimated the corrosion risk in the context of the CO_2SINK project (see 6. Research). The estimate looks into whether corrosion occurs, and if so, which type (local or surface corrosion), as well as corrosion kinetics (how high is loss of material per time and the corresponding risk of when the pipeline will break). The estimate was carried out for the materials used in Ketzin (Brandenburg, see 6. Research). The probability of a damage with gas blowout for an operation period of 3-4 years was estimated low. d) **Storage**: For the remaining injection wells, risk assessments were carried out for the development of corrosion. Drilling through cap rock cannot be reversed. Holes are sealed, generally with concrete. These remaining drill holes, which are sealed with concrete are here referred to as remaining injection wells. This sealing will be exposed to acidic formation waters. Risk assessment is carried out in different research programms for reactions with the geological environment. **Quantitative RA**: The Federal Institute for Materials Research and Testing (BAM) studied the durability based on the laws of growth of corrosion for Ketzin (Brandenburg, see 6. Research). In addition, experience was gained with statistical models of durability based on failure probability distribution. Durability studies focus on the steel pipes used. The process over time of local corrosion or wall loss are combined to discuss the probability of a gas blowout. Statistical models of durability take uncertainty in measurements into account or deliver a distribution of probabilities of an incident. **Qualitative RA**: Application of qualitative modelling through cause-and-effects diagrams: these diagrams explain the effects of physico-chemical parameters in a qualitative way and are thus the precursor of numeric models. **Modelling of accident scenarios**: In a UFOPLAN research project (to be concluded in summer 2010) (also refer to 6. Research) accident and major accident scenarios for storage process and their possible impacts are being studied.
Korea	Not yet.
Netherlands	Answer to all the questions is yes. **Acceptance criteria – Short description of the methodology**: Accepted methodology is laid down in rules for risk calculations and published in official documents.

Norway	a) **Pipelines**: In general very little statistical data available for a quantitative risk analysis. External risks more or less the same as for HC pipelines. Internal risks, corrosion and water plus impurities. Specific max limits not known.
Slovak Republic	No
Sweden	No
Switzerland	No. **Acceptance criteria – Short description of the methodology**: This topic is covered by research being carried out by the Swiss CARMA project on public perception and legal aspects of CCS (SP 5; http://www.carma.ethz.ch/c_project/subproj/sub_5).
Turkey	--
United Kingdom	Do you have any experience of risk assessment of CO_2 for CCS, for: a) **Pipelines**: Yes b) **Capture plant**: Partial c) **Injection facilities**: Partial d) **Storage**: No **Quantitative risk assessment** carried out for gaseous CO_2 pipeline and quantitative consequence analysis for releases from semi-refrigerated storage to inform whether CO_2 should be a dangerous fluid/substance under UK Pipeline Safety Regulations or EC Seveso Directive. **Qualitative HAZID** carried out for capture, pipeline and injection (this was done for IEA GHG and HSL report is available from them mike@ieaghg.org) **Acceptance criteria**: **Short description of the methodology**: HSE have developed major hazards dose criteria (SLOT and SLOD) for CO_2. HSE has criteria for land-use planning advice in the vicinity of hazardous installations which are in terms of the risk of a SLOT dose. For pipelines a range of hole sizes was used. PHAST was used to model hazard ranges to SLOT criteria. Total individual risk was calculated using HSE's Toxic Risk Assessment Methodology (TRAM) which is a spreadsheet based risk calculator. Failure rates were based on hazardous liquid pipeline data following a review of available data and taking into account that CO_2 pipelines have additional failure modes compared with hydrocarbon pipelines. For semi-refrigerated storage, a pre-release version of PHAST with CO_2 modelling capability was used.

8. (Risk) Communication

a) Is the public being informed about plans for new and/or the operation of existing CO_2 capture, transport and storage facilities? If yes, how?	
Belgium	There are neither existing capture, transport or storage facilities in Belgium, nor any planned in the immediate future. Therefore, the issue of public communication is not yet on the table.
Canada	Various means are used to inform the public about CCS activity in Canada. A lot of information is available on the internet. For example, the Canadian CCS Network (www.ccs101.ca) is a federal/provincial/territorial government-based network whereby government officials work collaboratively to address key CCS issues of common interest across Canada. One of the objectives of the Network is to provide public education and outreach on CCS. (Source: CCS101). In addition, common practice is for companies to inform the surrounding community of CCS activity through mail-outs, door-to-door, etc.
Czech Republic	No, as there is not yet such a plan.
France	Yes. Public enquiry, Internet websites.
Germany	In the past the public has been informed on capture and storage facilities primarily by the companies or company associations (or company combinations such as IZ Klima, Informationszentrum Klimafreundliches Kraftwerk). In the Coalition Agreement of November 2009, the federal government made a commitment to promote public acceptance for the further development of CCS technologies. Examples for current information policies: Vattenfall runs a local information office in a potential storage site area (Beeskow). Some public authorities (e. g. Federal Institute for Geosciences and Natural Resources (BGR), State Authority for Energy, Mining and Geology (LBEG) Brandenburg) run websites on CCS. There have been public hearings in potential storage areas.
Korea	Yes. However, minimum level information from mass media.
Netherlands	Yes, through means of various media.(local) newspapers, (local) television, internet, public hearings, brochures etc.
Norway	Company communication, newspapers and media in general.
Slovak Republic	No
Sweden	--

Switzerland	Not applicable.
Turkey	--
United Kingdom	All information is freely available on a vast number of web sites. EU project has full declaration requirements. Planning development organisations and others such as IEA GHG have arranged conferences. Public perception studies have been carried out by various organisations such as the Tyndall Centre in Manchester the DNV project “Pipetrans” intends to carry out such studies. IF COMAH is to apply the public within defined PIZ’s will be properly informed.

<table>
<tr><th colspan="2">b) Have any concerns been raised by the public or public organisations about the safety aspects of CCS projects? If yes, what has been your experience? What are the main concerns of people?</th></tr>
<tr><td>Belgium</td><td>Public awareness vis-à-vis CCS is very limited in Belgium. There is a general lack of information on CCS; Belgian media and politics don’t seem to put CCS high on the agenda. Some environmental NGO’s remain sceptical; others seem to accept the value of CCS in the battle against climate change.</td></tr>
<tr><td>Canada</td><td>Research was conducted in 2004 and 2005 to investigate the public’s perceptions concerning “geological disposal of carbon dioxide”, first through focus groups, and subsequently through a national survey. The research showed that the public was most concerned about unknown future impacts, contamination of groundwater, the risk of a CO_2 leak, and harm to plants and animals. However, the technology is perceived to be less risky than normal oil and gas industry operations, which are generally accepted in Canada, despite occasional accidents and environmental problems. (Source: Sharp et al.).</td></tr>
<tr><td>Czech Republic</td><td>No.</td></tr>
<tr><td>France</td><td>Yes. Main concerns are potential impacts on health coming from CO_2 leak, and impacts on soil (soil acidification due to CO_2 going up by micro-cracking).</td></tr>
<tr><td>Germany</td><td>The public around storage sites has massive concerns about consequences for the local community, e. g. estate prices, tourism, property damage caused by induced seismicity, and why to place additional risks in our backyard.

There also have been concerns about more general and political issues: General technical aspects:
– Recycling of CO_2 instead of deposition
– Concerns about unpredictable risks of CO_2 storage for health, environment and safety, for example:
o Uncontrolled release of CO_2 from storage could lead to suffocation
o Contamination of drinking water and soils with CO_2
o Enrichment of groundwater with CO_2
o Dispersion of CO_2 underground?
o Uncontrolled displacement of formation water, including risk of salinisation of groundwater due to CO_2 storage
o Risks from other combustion residues in the CO_2 stream apart from the actual CO_2 to be stored.
o Tectonic changes (uplift, earth tremors)
o Risks of accidents
o Special measures in the area of crossings of CO_2 pipelines, e.g. with supply and disposal lines.

Political aspects:
– Royalties for storages?
– Why CCS as we should promote renewables?
– Why help coal power?
– Will the CCS bill deteriorate my legal position?
– Who is liable for damages to groundwater due to CO_2 storage?</td></tr>
</table>

	– Fear of real estate owners that their property may lose value. Such concerns of the public were voiced when the public was informed about potential CO_2 storage sites in both Schleswig-Holstein and Brandenburg.
Korea	Not yet specific one. But, in 2007, an accident of oil leakage into the west sea from oil-transportation ship damaged the biological system of the sea fatally. Similar concern can be raised about ship transportation.
Netherlands	In the case of the Barendrecht location people have raised concerns about the risks of a CO_2-storage underneath their neighbourhood might cause for them. The main concerns are that a leakage might occur and inhabitants might be deadly affected by this (asphyxiation, toxic effects). People are anxious about possible incidents such as a blow-out (during injection) and long-term effects such as leakages through various possible paths.
Norway	To date few concerns raised from the public on HSE issues related to CCS (more on the political issues). Potential health issues related to release of amines and amine derivatives (nitros+++) have been raised.
Slovak Republic	No
Sweden	--
Switzerland	Not applicable regarding domestic CCS projects.
Turkey	--
United Kingdom	There has been some concern expressed fuelled by media coverage, e.g. unsafe to sleep in ground floor rooms if CO_2 stored underground. At present there is not a large public awareness of CCS or the plans to transport high pressure CO_2 by pipeline.

c) Is there any possibility for the public to participate in the decision making process regarding CCS projects? If yes, how? • **In what way are the remarks made by the public addressed by the competent authority? Does the competent authority react in any way on remarks made by the public? If yes, in what way?** • **Do the official decision documents contain a chapter on communication with the public and/or remarks made by the public?**	
Belgium	Currently there are no CCS projects planned in the immediate future.
Canada	Public consultation is part of the environmental assessment process so the public has the opportunity to participate if an environmental assessment is triggered. Also, the public could have the possibility to comment if CCS activity is discussed in town hall meetings. No information available with respect to the above two bullet points.
Czech Republic	Yes, the process should be similar to that with other important industrial projects. Such a project has to be officially announced and public participants (including NGOs) could make comments and afterwards representatives of government shall take these comments into account.
France	Yes. Public enquiry, Internet websites. • **In what way are the remarks made by the public addressed by the competent authority? Does the competent authority react in any way on remarks made by the public? If yes, in what way?** A report based on remarks expressed during the public enquiry is written. It is examined by the competent authority. Remarks can be taken into account in official decision document. • **Do the official decision documents contain a chapter on communication with the public and/or remarks made by the public?** Environmental legislation includes disposals on communication with the public.
Germany	As the EU Directive 2009/31/EC has not yet been transposed into national law, there are no specific rules governing public participation relating to CCS. However, corresponding regulations for capture can currently be derived from the Federal Imission Control Act (BImSchG), and regulations for the operation of pipelines from the Act on the Assessment of Environmental Impacts (UVPG). The storage permit specified in the CCS Directive will be transposed into German law as a plan approval. German planning approval law attaches great important to participation of the public and the affected parties. Objections of citizens must be heard in the public enquiry held during the planning approval procedure in accordance with Article 73 of the Administrative Procedures Act (Verwaltungsverfahrensgesetz). As the plan approval must consider all public and private concerns, it is ensured that the competent authorities take such concerns into adequate account and carefully review the objections. Objections on which the public enquiry does not reach agreement are incorporated into the decision on the plan approval (Article 74 (2) VwVfG). The

	German government is also looking into the further options for public participation during the exploration of a potential storage site. The Land Brandenburg reported that additional regulations at the Länder level are not planned there. The mining law, which allows exploration of brine, only gives limited participation for the public. However, special field works (e. g. seismic, drilling) need consent of property owners. • **In what way are the remarks made by the public addressed by the competent authority? Does the competent authority react in any way on remarks made by the public? If yes, in what way?** • **Do the official decision documents contain a chapter on communication with the public and/or remarks made by the public?** In the strongly formalised planning approval procedure all public and private concerns have to be considered within a strict framework of procedural rules. Thus, it is one of the ultimate purposes of the planning approval procedure to formalise communication with the public and to properly inform about the results of that communication with the public.
Korea	It seems government, companies and institutes will participate in the decision making process in CCS mainly rather than the public.
Netherlands	Yes, through standard public participation procedures, that also applies to other environmental and spatial planning decisions. The environmental impact assessment is part of the decision making. People can react to the findings in the EIA-report and on the scope of the study. • **In what way are the remarks made by the public addressed by the competent authority? Does the competent authority react in any way on remarks made by the public? If yes, in what way?** The competent authorities react on the remarks made by the public by addressing these remarks in a separate document or annex to the decision. In addition, the public is informed on special gatherings where it can also express their concerns or ask questions to officers and politicians. • **Do the official decision documents contain a chapter on communication with the public and/or remarks made by the public?** See above.

Norway	Yes, there will be a process that includes the public through consequence evaluations. • **In what way are the remarks made by the public addressed by the competent authority? Does the competent authority react in any way on remarks made by the public? If yes, in what way?** In general all information of this type will be public in Norway. • **Do the official decision documents contain a chapter on communication with the public and/or remarks made by the public?** Submitted plans will be made available for the public.
Slovak Republic	Not yet.
Sweden	--
Switzerland	Yes. • **In what way are the remarks made by the public addressed by the competent authority? Does the competent authority react in any way on remarks made by the public? If yes, in what way?** • **Do the official decision documents contain a chapter on communication with the public and/or remarks made by the public?** Switzerland is a confederation, with a federal government, a bicameral parliament and a federal supreme court. The territory consists of 26 cantons (states), each of which has its own government, parliament and cantonal courts. Constitutional law states that, unless legislative power is explicitly assigned to the confederation, the cantons are sovereign. In Switzerland federal legislation, decisions of parliament and certain international treaties are subject to an optional referendum; i.e. the people are entitled to pronounce on parliamentary decisions after the event. Furthermore, at cantonal level citizens may request that the People decide on a new law or a new amendment (cf. “The Swiss Confederation – a brief guide 2010”, page 16-17; http://www.bk.admin.ch/dokumentation/02070/index.html?lang=en). This entity also applies for CCS projects and the concomitant regulatory framework.
Turkey	At the present time[16] there are no CCS projects planned in the immediate future, nevertheless under access to information and Environmental Impact Assessment legislation, information is public and decision making process is open to participation.
United Kingdom	By the normal process of planning application, licensing, appeals, rejections and public enquiry. • **In what way are the remarks made by the public addressed by the competent authority? Does the competent authority react in any way on remarks made by the public? If yes, in what way?** All inputs to such enquiries are considered in a balanced way by the head of the enquiry this has worked to great effect in the past. A full report is typically issued. • **Do the official decision documents contain a chapter on communication with the public and/or remarks made by the public?** The CA will be one of a set of

[16] This information was provided in 2013 and therefore has not been taken into account for the analysis of the survey.

	statutory consultees at various stages of the planning implementation and operating phases of such technologies.

d) Lessons learned for other/future projects?	
Belgium	Not applicable.
Canada	The above-mentioned research showed that more public education about CO_2 and climate change is needed. The results indicated that climate change ranks very low in importance compared to other national issues. Also, the public seems to perceive CO_2 as more dangerous to their health than it actually is. Therefore, public education should stress that CO_2 is only dangerous to human health in high concentrations, and is of most concern because of its impact on the climate, and that climate change is a critical environmental issue. Also, the research showed that most Canadians have not previously heard of geological disposal of carbon dioxide, so they assume it is a new and untested technology. Therefore, information should be shared about the technology's safe history of use in the oil and gas industry, and its current use in both demonstration and commercial projects in Canada and in other countries. The research also showed that for the public to be supportive of the geological disposal of carbon dioxide, this technology needs to be presented as not being a replacement to other alternatives to reduce greenhouse gas emissions, but rather as a short-term solution used simultaneously with other long-term emission-reduction and lifestyle-changing solutions. (Source: Sharp *et al.*). Canada's CO_2 Capture and Storage Technology Roadmap reiterates that the public needs to be better informed of CCS and any benefits and challenges related to its application, and that open and transparent public outreach and education needs to take place with verifiable information made available to the public. (Source: CCSTRM).
Czech Republic	--
France	Not yet.
Germany	The public should be informed as early as possible in an objective and comprehensive manner. The operators should accordingly seek active dialogue at an early stage and conduct this dialogue objectively and appropriately.
Korea	--
Netherlands	Risk communication turns out to be an important policy instrument. For example if a risk assessment shows that the risks of a certain activity are not very high compared to other industrial risks, people may still perceive them to be very high. Authorities, and others involved should be aware of that.

Norway	http://www.ptil.no/getfile.php/PDF/Ptil%20CCS%202008.pdf http://www.ptil.no/48346004-34A0-40DE-9FE2-F59FF30CABC9/FinalDownload/DownloadId-6E6A52DE2F270AA75A41921D8D6164BA/48346004-34A0-40DE-9FE2-F59FF30CABC9/getfile.php/PDF/SINTEF-Report-CO2-injection-well-integrity.pdf
Slovak Republic	No comment.
Sweden	--
Switzerland	Not applicable.
Turkey	--
United Kingdom	Documents are available under FOI and freely accessible if COMAH applies, certain restrictions on commercial confidentiality obviously apply in certain circumstance.

Appendix attached to the Canada response to the Questionnaire

References

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http://www.iea.org/subjectqueries/ccs_legal_countries.asp

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