Proceeding Workshop I on licensing activities: Best practices in CCS demonstrations

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1 Executive Summary

This document is the first report of the five-year (2009-2013) research project, that has been carried out within the framework of the CATO-2 program. The mission of the CATO-2 program is to facilitate and enable the integrated development of CCS demonstration sites in the Netherlands. The program's ambition is to help support the realisation of two or more demonstration sites where the complete integration of CO_2 capture, transport and storage will be demonstrated in the Netherlands before 2015.

The objective of this research project, CATO-2-WP4.2, is to identify best practices from permitting and certifying CCS activities at designated CCS sites in the Netherlands (offshore as well as onshore urban and rural areas). It will bring together all findings resulting from the project and make these available to a platform consisting of the site operators of the CCS projects, considered within the CATO-2 program. It will help in particular to resolve barriers of regulation, monitoring & verification, and public perception, and thus facilitating and enabling the introduction of CCS demonstrations, as well as a further development of CCS technologies in the Netherlands.

Within the framework of this CATO-2 project a questionnaire to the location managers of the CCS projects in the Netherlands has been prepared by the project partners. It includes questions on general aspects of the operation, permit issues, environmental impact assessments, ETS monitoring, risk management of geological storage, and expectations of the location managers vis-à-vis this project. The questionnaire was made available on-line to 12 location managers, of which 9 did fill in the questionnaire. In order to further an understanding of the responses, additional interviews, including additional questions, were conducted with the location managers.

The results of the questionnaire and the subsequent interviews with the location managers of the CCS projects considered, have led to some conclusions and recommendations, as presented below.

General aspects location

All the projects considered are still in the development phase and none are operational yet. The capture technologies of the CCS projects considered are *post-combustion*, *pre-combustion*, and *oxy-fuel*. In addition, in two of the concerned CCS projects the CO_2 is a 100% pure stream. In most of the considered CCS projects, the transport of CO_2 from the capture site to the storage site will take place through newly built pipelines. The majority of the storage sites in the projects considered are related to natural gas production, one site is also related to oil production. None of the natural gas or oil production sites are abandoned yet. In addition, two aquifers are also selected for CO_2 storage.

Permitting of CO_2 capture and storage projects

At least ten Dutch acts and regulations are deemed to be relevant for CCS projects. Based on the responses to the questionnaire, the total length of the permitting procedure seems to be between 2 to 3 years. As a number of interviewees (operators of CCS projects or parts of the chain of a

CCS project) pledge for an 'encompassing package covering CCS activities with a strong involvement of the government', it is highly important that the authorities involved (government and/or province or municipality) realise that a strong involvement with facilitating of CCS projects does not allow unnecessarily lengthy permitting procedures. There have been unsatisfactory experiences with the permitting of the first few CCS projects. However, this was generally not due to specific laws or regulations but due to conflicting views on the requirements for CSS at different levels. This in itself makes the proposed 'packaging' an option to be seriously studied.

Environmental Impact Assessment

From the observations based on results of the questionnaire, it can be concluded that the non-CO_2 environmental impacts are considered relevant, however, are not yet in the picture as a major CCS issue or acceptance risk in the early stages where current CCS pilot projects are in. This assessment is primarily based upon the current properties of power generation technology, the general working mechanisms of CCS technologies and international literature. Nevertheless, information and support in the assessment of non-CO_2 environmental impacts over the full life cycle are welcomed.

Underground storage

Based on the results of the questionnaire it appears that standard procedures and processes for risk management are currently not available in relation to underground storage issues. This is probably due to the early stage of preparation of storage operations. None of the projects have started to operate and therefore knowledge on the procedures and processes, which will be tested during operation, is not yet available. Therefore, mostly general risk assessments have been performed and monitoring plans, abandonment plans and preventive and corrective measures are described in non-specific manners, if available.

Monitoring of emissions for the EU ETS

The general impression is that for most of the projects monitoring for EU ETS is not an important issue yet. Not only because of the stage of the project, but in some cases also because they don't feel responsible for it and leave this to the companies who will transport and store the CO_2.

There is some concern about the effect of a too comprehensive monitoring programme. Implementation of monitoring systems for all imaginable parameters could suggest that processes are not completely understood. And lay people could easily draw the conclusion that when measurements take place, there also something will be measured (think of CO_2 seepage to the surface). Measurements should take place only when it makes sense.

A template of a generic monitoring plan would be very welcome.

Distribution List

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Document Change Record

(this section shows the historical versions, with a short description of the updates)

Version	Nr of pages	Short description of change	Pages
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Table of Content

2 Applicable/Reference documents and Abbreviations

2.1 Applicable Documents

(Applicable Documents, including their version, are documents that are the "legal" basis to the work performed)

	Title	Doc nr	Version date
AD-01	Beschikking (Subsidieverlening CATO-2 programma verplichtingnummer 1-6843	ET/ED/9078040	2009.07.09
AD-02	Consortium Agreement	CATO-2-CA	2009.09.07
AD-03	Program Plan	CATO-2-WP0.A-D.03	2010.09.30

2.2 Reference Documents

(Reference Documents are referred to in the document)

	Title	Doc nr	Issue/version	Date

2.3 Abbreviations

CBA	Cost Benefit Analysis
CHP	Combined Heat and Power
CCS	Carbon Capture and Storage
DAP	Delft Aardwarmte Project
ECBM	CO_2 Enhanced Coal Bed Methane
EGR	CO_2 Enhanced Gas Recovery
EIA	Environmental Impact Assessment
EOR	CO_2 Enhanced Oil Recovery
EU ETS	European Union Emission Trading System
GdF	Gaz de France
GIIP	Gas Initially In Place
IGCC	Integrated (coal) Gasification Combined Cycle
IRR	Internal Rate of Return
LCA	Life Cycle Analysis
NAM	Nederlandse Aardolie Maatschappij
NER	Nederlandse Emissie Richtlijn
NOx	Nitrogen Oxides
PM	Particulate Material
POT	Payout Time
RCI	Rotterdam Climate Initiative
WP	Work Package
ZEPP	Zero Emission Power Plant

3 Introduction

3.1 General

This research project has been carried out within the framework of the CATO-2 program. The mission of the CATO-2 program is to facilitate and enable the integrated development of CCS demonstration sites in the Netherlands. The program's ambition is to help support the realisation of two or more demonstration sites where the complete integration of CO_2 capture, transport and storage will be demonstrated in the Netherlands before 2015.

3.2 Project objective

The objective of this research project, CATO-2-WP4.2, is to identify best practices from permitting and certifying CCS activities at designated CCS sites in the Netherlands (offshore as well as onshore urban and rural areas). It will bring together all findings resulting from the project and make these available to a platform consisting of the site operators of the CCS projects, considered within the CATO-2 program. It will help in particular to resolve barriers of regulation, monitoring & verification, and public perception, and thus facilitating and enabling the introduction of CCS demonstrations, as well as a further development of CCS technologies in the Netherlands.

3.3 Description of work

Within the framework of this CATO-2 project a questionnaire to the location managers of the CCS projects in the Netherlands has been prepared by the project partners (Appendix A). It includes questions on general aspects of the operation, permit issues, environmental impact assessments, ETS monitoring, risk management of geological storage, and expectations of the location managers vis-à-vis this project. The forthcoming of a questionnaire was announced during the Program Council on 30 October 2009, and the location managers reacted positively.

The questionnaire was made available on-line to 12 location managers, 9 of which did fill in the questionnaire. In order to further an understanding of the responses, additional bilateral interviews, including additional questions (Appendix B), were conducted with the location managers.

The results of both the questionnaire and the subsequent interviews are described and discussed in this document, which is the first report of the five-year (2009-2013) research project within the CATO-2 program.

3.4 Report outline

Chapter 5 gives a short description of the CCS projects in the Netherlands, after which different aspects and data regarding the sub-processes of the CCS projects (capture, transport, storage) are presented. At the end of this chapter special attention is directed towards the investment decisions of the CCS projects, followed by a communication strategy of the considered CCS projects with the media.

Chapter 6 gives a view of a number of important permits that are needed for CCS projects, based on laws and regulations that are in place. It also provides a view of the experience with these laws and regulations in Dutch CCS projects that are in the stage of implementation or (firm) planning, and focuses on suggestion how to improve the permitting process in the Netherlands.

The results related to Environmental Impact Assessment are presented in Chapter 7. Chapter 8 refers to the results related to underground storage, with focus on risk assessment procedures currently used/performed, monitoring procedures stated in the monitoring plan, and preventive and corrective measures defined. Finally, the results related to monitoring of emissions for the EU ETS are discussed in Chapter 9.

It should be mentioned that for the sake of confidentiality, the data in tables 6.1, 6.2, 7.1, 8.1 and 9.1 is presented at random.

4 General aspects location

This chapter starts with a short description of the CCS projects in the Netherlands, after which different aspects and data regarding the sub-processes of the CCS projects (capture, transport, storage) are presented. At the end of the chapter special attention is directed towards the investment decisions of the CCS projects, followed by a communication strategy of the considered CCS projects with the media.

The chapter is mostly based on the responses of the location managers of the CCS projects to questions 1-38 of the questionnaire.

4.1 Description of the CCS projects in the Netherlands

Some general characteristics regarding the CCS projects in the Netherlands, e.g. size, transport distance, type of project, are presented in Appendix C. A short description of each of the CCS projects follows below.

4.1.1 PEGASUS project

SEQ International is working on an integrated feasibility study for the development of a large-scale CCS demonstration project. The project concerns capture of CO_2 at a power plant, transport and storage of CO_2 in an offshore geological storage site. The project is planned to be located in the IJmond region in the Netherlands.

The project is split into two phases. The first phase of the project taking 2 years consists of a demonstration unit of 30 MW_e, realizing 4000 to 5000 operating hours, with an investment decision to be made in 2010. The second phase starts in 2013, after the required go/no-go decision (based on costs/efficiency), and concerns a 400 MW_e power plant (low-calorific value gas).

The capture technology involved in this project consists of the oxy-fueled Zero Emission Power Plant (ZEPP)-concept, based on combustion of natural gas, or low-calorific fuel, with pure oxygen in a specially designed gas combustor; in fact it is a downscaled rocket engine. Construction and testing of this highly innovative gas system has since 2008 been initiated at a test site in California, and a demonstration installation is available for shipment to IJmond.

Phase 2 is planned 2 years after the first phase of the project. Captured CO_2 is either stored in depleted gas fields offshore the Dutch Continental Shelf, or transported to oil fields for use in an EOR (Enhanced Oil Recovery) project. The main reason for the selection of this storage site is the available infrastructure, (relatively) close to offshore production and storage facilities and the generic industrial environment of the area

The continuation/realisation of the project (phase 1 and phase 2) depends on the availability of the required financial support, among others from the Dutch government. As far as this is not clear enough, no investment decision will be made.

4.1.2 ROAD project

The ROAD project is the joint CCS demonstration project of E.ON and Electrabel. A new coal-fired unit will produce 1070 MW of electric power. This CCS project will become operational in 2015, and around 1.1 Mtonnes CO_2 per year will be captured. This corresponds to the equivalent of 250 MW_e. The storage location will be offshore (25 km of pipeline to one of TAQA's offshore gas or oil fields).

4.1.3 CO_2 storage at Chemelot site in Geleen

At Chemelot three parties - the Dutch company DSM, the French/Dutch company Cofely SUEZ/GTI, and the Belgian company VITO - are collaborating in the demonstration of a CO_2 storage project using the space between and below coal seams.

The CO_2 to be injected and stored comes from an ammonia plant that currently produces 1 million tonnes of ammonia per year. For each tonne of ammonia produced, around 1 tonne of pure CO_2 is produced. Currently, 50% of the CO_2 is used for other industrial purposes (soft drinks industry and urea production), the remaining CO_2 is vented to the atmosphere.

The project is split into two phases. During the first phase a small amount of about 10 kilo tonnes CO_2 will be injected into the storage reservoir. The main goal of this first phase is to learn more about injection technology. If the initial tests prove successful, the CO_2 storage project will be scaled up to store 5 million tonnes of CO_2 over a period of 10 years. It could be possible to produce a small amount of methane from the coal bed but the project is primarily focussed on storage.

The main reason for the selection of this site is that the injection well can be situated on the DSM site. The Chemelot site is an industrial site which is not populated. In case of a large-scale project, the horizontal migration of CO_2 in the underground reservoir could result in CO_2 storage under a populated area. The area is medium densely populated.

4.1.4 Magnum project

The Magnum project concerns a 1200 MW multi-fuel (coal, biomass, natural gas) power plant, that would initially be suited to natural gas but ready for coal gasification. Pre-combustion CO_2 capture is planned to be integrated from the start with the objective to reduce the specific CO_2 emission from coal to that of a state-of-the-art natural gas-fired power plant.

CCS operation after the demonstration phase would be driven by need for knowledge and market circumstances.

4.1.5 RWE project Eemshaven

RWE is planning a 1600 MW coal-fired power plant in Eemshaven together with a 200,000 tonnes per year (equivalent to 35 MW) post-combustion CO_2 capture R&D unit.

The main reason for the selection of this site is the nearby storage facilities..

4.1.6 Shell Barendrecht project

The 'Barendrecht' CCS project is based on pure CO_2 captured from a hydrogen factory of Shell in Pernis. Currently CO_2 is partly vented to the atmosphere and partly used for other purposes (greenhouses, soft drinks industry). For the CCS project CO_2 will be compressed and transported in gaseous form (40 bar) via a pipeline with a length of 20 km to Barendrecht where it will be stored in a depleted gas field. CO_2 will be transported by the company OCAP.

The CCS project is envisioned to start in 2012 and will be operated for some 30 years.

4.1.7 TAQA P18 project

The TAQA P18 project concerns an offshore CO_2 storage demonstration project. TAQA Energy B.V. operates the P15 and P18 oil and gas reservoirs and production facilities 20 to 40 km offshore Rotterdam. After cessation of production CO_2 will be transported via a new 20 km pipeline to platform P18-A from where it is stored.

Phase 1 - via the P18-A platform CO_2 can be injected into several depleted gas reservoirs using multiple injection wells. The combined effective storage capacity accessible from this platform amounts to around 30 million tonnes of CO_2. The effective storage capacity will depend on the maximum reservoir pressure.

Phase 2 - After natural gas production ceases across the P18-A platform, the existing pipeline to P15-ACD can be used to transport CO_2 to this central facility from where CO_2 can be distributed to the P15 reservoirs, providing an additional 30 million tonnes of effective storage capacity.

The main reason for the selection of this site was presumably based on distance and reservoir characteristics, and the fact that it can be used and is available in time for near-shore CO_2 storage.

4.1.8 Wintershall Q08 project

Q08-A is a depleted gas field with a direct pipeline towards the Q08-A Terminal next to the premises of Corus. The platform is intact and has 3 former production wells. When storing CO_2 the OCAP pipeline is assumed to be used. In that case a pipeline of just several kilometres will need to be constructed. Per year around 1 Mtonne is planned to be stored. Wintershall is specifically the storage operator but also takes care of the compression and transport from the site of the Q08-A Terminal.

The main reason for the selection of this offshore site is that the reservoir is depleted and infrastructure is available. Also, a feasibility study performed by TNO researched multiple sites in the Dutch North Sea. The other sites investigated in the study do not have a separate pipeline, which can therefore not be used to transport CO_2 at present and/or in the very near future.

4.1.9 DAP project

In the DAP project (Delft Aardwamte Project) the CO_2 captured at a CHP plant (post-combustion) will be co-injected with retour (cold) water of a geothermal project into an aquifer. The site is located within built-up area with university offices and laboratories.

The main reason for the selection of this site is the potential of geothermal energy production and use, with co-injection of CO_2 as part of a research oriented project.

4.1.10 CRUST project

The Gaz de France ORC project (Offshore Re-injection of CO_2), part of a Dutch study known as CRUST (CO_2 Re-use through Underground STorage), has been re-injecting CO_2 since April 2004 into the K12-B offshore natural gas field in the North Sea. The K12-B field originally contained natural gas with a CO_2 content of around 13%. It has been in production since 1987 and is now almost depleted. The gas produced is treated on the platform and the CO_2 extracted from the natural gas is re-injected into the reservoir.

4.1.11 CO_2 Catch-up Buggenum

Nuon Energy Sourcing, the Delft University of Technology, ECN and KEMA are cooperating to test pre-combustion CO_2 capture at the Willem Alexander integrated coal gasification combined cycle (IGCC) plant in Buggenum. The pilot project aims to:

- Test a range of parameters representative for Magnum in a pilot plant to verify the technology performance and operation window in the field environment;
- Identify and mitigate potential risks associated with the novel application of the selected technology;
- Optimize design and technology performance;
- Gather operating experience;
- Prepare for large-scale application in Nuon Magnum. The results produced in the pilot plant must be applicable for the development of state-of-the-art tools to be applied in the design process of the large-scale capture installation in the Magnum IGCC plant;
- Test new technologies (catalysts, solvents).

4.1.12 CO_2 capture project Twence B.V.

This concerns an R&D project on CO_2 capture (post-combustion) at the waste processing plant Twence B.V.

4.2 Capture

Several CO_2 capture technologies have been described by the considered CCS projects:

- Post-combustion (CO_2 source: 2 coal-fired power plants, 1 combined heat and power plant),
- Pre-combustion (CO_2 source: integrated (coal) gasification combined cycle plant),
- Oxy-fuel (CO_2 source: gas-fired power plant).

In two of the concerned CCS projects the CO_2 is a 100% pure stream:

- The Chemelot site concerning the DSM ammonia production plant;
- The Barendrecht project concerning a hydrogen plant of Shell at Pernis.

4.3 Transport

4.3.1 CO_2 transportation options

Choices need to be made in CCS projects concerning using existing infrastructure (pipelines, platforms) or developing new transportation infrastructure. In the latter case also choices on dimensions of the pipeline can be made. Besides pipelines, ship transport can be considered.

In most of the considered CCS projects, the transport of CO_2 from the capture site to the storage site will take place through newly built pipelines. In one case besides a newly built pipeline also transport by ship, or through the existing gas pipeline are reported as options.

The new pipeline to be built at Barendrecht would be over dimensioned, so that possibly more projects could be connected and make use of that pipeline.

4.3.2 Required operational transport conditions

The operational transport conditions (pressure, distance, temperature, and purity) to be met by designing are as follows for the considered CCS projects:

- CO_2 transport at the Chemelot site would take place at 100 bar, 5-10ºC (=liquid), and 99% purity.
- At Barendrecht the transportation pressure would be 40 bar, and CO_2 would remain in gaseous form.
- Concerning the Wintershall project a 10 inch pipeline is available between the Q8-A Terminal site and the Q08-A platform. The CO_2 should be transported at supercritical condition, because otherwise the capacity of the pipeline would be too low. A compressor is available on the Q8-A Terminal site that can be used to compress the CO_2, and to transport it to the Q08-A platform. The CO_2 will probably be transported with a pressure of 80 bar, which is the P_{max} of the pipeline. This means that the CO_2 needs to be heated during the expansion at the platform.
- The operational transport conditions at TAQA project are subject to a currently ongoing engineering study. Results are expected late 2010.
- Concerning the remaining projects, either the way of transport should still be decided upon, or the operational transport conditions have to be defined by the pipeline operator, or no information is available.

4.3.3 Design and material specifications

The design and material specifications (dimensions, material, lining) to be applied for the defined transport unit(s) are either confidential, or still have to be determined, defined by the pipeline operator, or are subject to engineering study.

4.4 Storage

4.4.1 Industrial history of the storage site

The majority of the storage sites in the considered projects are related to natural gas production, one site is also related to oil production. None of the natural gas or oil production sites are abandoned yet. In one case no reservoir choice has been made yet. The CO_2 storage at the Chemelot site in Geleen is a saline aquifer without other applications. Chemelot is a chemical complex with 54 chemical installations. The underground of this complex has not yet been used in the past. The aquifer considered in the DAP project has no other application; this aquifer is on top of a reservoir which is to be used for geothermal energy production.

4.4.2 Potential CO_2 volume of the reservoir

In case of two projects either no reservoir choice has been made yet, or the reservoir has not been confirmed yet. The capacity of the aquifer for the DAP project is not mentioned. One reservoir has potentially sufficient CO_2 storage volume. However, the available volume for the considered CCS project would depend on other CO_2 suppliers to the same location.

One reservoir has a CO_2 storage capacity of up to 8 Mtonnes. Other reservoirs have potential CO_2 storage capacities of more than 10 Mtonnes.

The P18 offshore reservoir has a storage capacity of 60 Mtonnes. The potential CO_2 volume would depend on the pressure regime. The maximum pressure must still be decided upon, probably around 80 bar (supercritical CO_2), as gas phase transport would not be practical considering the scale. This might require insulation of the pipeline in order to mitigate cooling of CO_2.

4.4.3 Potential conflicts of land use at the ground level of the storage site

The majority of respondents do not expect any potential conflicts of land use at the ground level of the storage site. From these respondents one has the confidence that in case of any conflict, Gasunie or NAM (acting on behalf of a CO_2 transport consortium) as experienced companies would be able to negotiate with the land owners.

Concerning the DAP project, potential conflicts are expected with respect to the built-up area. However, the municipality does not decide on the geothermal and CO_2 capture and storage project. Other potential conflicts could arise if the CHP plant would be enlarged, which may increase the CO_2 capture potential.

4.4.4 Existing infrastructure that may affect the storage site

In case of five of the nine projects existing oil/gas production infrastructure (e.g. wells, platform) may affect the storage site positively or negatively. At four of these five projects also pipelines or cables are present that might affect the storage site positively or negatively. At TAQA site re-use of the platform and wells is foreseen. In case of platforms if possible, they are usually re-used, while the pipelines are sometimes re-used and sometimes not re-used.

In one case no reservoir choice has been made yet, and regarding the remaining two projects no information is available.

4.4.5 Acquiring access to private properties for geophysical investigations

One of the nine projects, namely Barendrecht, reports on the necessity to acquire access to private properties at little effort, because of the pipeline.

In case of the DAP project no problem is foreseen based on new drilling technology with different materials for the piping. This technology is first applied at Pijnacker. The geothermal project involves three doublets (hot and cold water), among which one doublet at the CHP site in Delft.

4.4.6 Specific use of the reservoir

In addition to CO_2 storage application of the reservoirs considered, in three of the nine storage sites also potential CO_2 enhanced oil/gas recovery is reported. In such cases the oil or gas production company may optimise the process, resulting in additional oil or gas recovered.

4.4.7 Potential conflicts of use in the subsurface at the storage location

In four of the nine considered CCS projects one or more potential conflicts of use in the subsurface at the storage location might occur. These projects and their corresponding potential conflicts are as follows:

- *Chemelot project:* When CO_2 is stored, the present coal layer cannot be produced from this site (which is not assumed due to the depth of the coal bed). A possible spin-off could be ECBM from the coal bed above the CO_2 storage.
- *Magnum project:* Pre-selection by companies engaged in gas production narrows the range to gas fields that are suitable for CO_2 storage, without, e.g., claims for natural gas storage or extending gas field production lifetime.
- *TAQA project:* The gas reservoirs are never completely empty, but at a certain moment not profitable anymore. New CCS activities could change this economic perspective. If you decide to continue producing natural gas from these nearly empty reservoirs when you start injecting CO_2 eventually the extracted gas will have a too high CO_2 content (as a result of breaking of the CO_2 front). This decision should be agreed upon carefully with the field owners.
- *DAP project:* If oil or gas in economical quantities would be discovered, this would jeopardize both the geothermal project and CO_2 capture and storage. Drinking water is found on 300 m depth (if applicable). Therefore, no potential conflict is expected with respect to groundwater extraction. A heat/cold storage project is applied up to a maximum of 500 m depth. However, this does not interfere with the geothermal energy and CO_2 storage project.

4.5 Investment in CCS projects

Different reasons have been reported for development of the CCS projects. Concerning the coal-based power plants, according to the Dutch national programme 'Clean and Efficient' there are two options to be applied for the reduction of CO_2 emissions: one is the co-firing of biomass, and the other is carbon capture and storage. In some cases both options have been applied by the energy companies. For the owners of offshore gas platforms, the CCS option has been considered as a business opportunity and a new application for their assets instead of expensive decommissioning.

Regarding the DSM plant in Geleen, as ammonia is the basic building block of the world nitrogen industry, their CO_2 production will be capped. When the penalty for CO_2 emissions would become too high, the transfer of costs to consumers could result in a very expensive product. CCS could then be seen as an alternative in order to prepare for EU ETS.

DAP is a special research oriented project. Normally the injection of supercritical CO_2 in an aquifer would create a CO_2 'lake' above the aquifer, but in case of injection of retour (cold) water saturated with CO_2, this does not happen. Next to CO_2, also NO_x from the CHP plant will simultaneously be injected.

4.6 The media

Regarding the Barendrecht project, Shell did carry out a media briefing and made contacts with the media from the early stage of the project. Shell has been very active to inform the public on their intended CO_2 transport and storage project.

DSM has approached both the regional and local authorities and interested groups (Province, municipalities, residents' associations), as well as newspapers to provide information about the Chemelot project. They were also approached unintentionally by the media.

Concerning the DAP project, there have already been two contacts with the media: one in a local paper (initiative of journalist), and another time in a scientific magazine. Also in case of the Nuon project (CO_2 capture at IGCC plant Eemshaven) information has been provided to the media.

Regarding the remaining projects, either no contact has been made yet with the media, or no information is available. According to one of the site operators due to the lessons learned from Barendrecht, they have become very careful in contacting the media. They work on a communication plan on CCS. Another site operator mentions that they will report on the usefulness and the necessity of CCS in due time.

4.7 Conclusions and recommendations

All the projects considered are still in the development phase and none are operational yet. The capture technologies of the CCS projects considered are *post-combustion*, *pre-combustion*, and *oxy-fuel*. In addition, in two of the concerned CCS projects the CO_2 is a 100% pure stream. In most of the considered CCS projects, the transport of CO_2 from the capture site to the storage site will take place through newly built pipelines. The majority of the storage sites in the projects considered are related to natural gas production, one site is also related to oil production. None of the natural gas or oil production sites are abandoned yet. In addition, two aquifers are also selected for CO_2 storage.

5 Permitting of CO_2 capture and storage projects

There is still relatively little experience with permitting of CO_2 capture and storage (CCS) projects. Among the considered projects, the 'Barendrecht project' (Shell) stands out in terms of the stage of permitting. Paragraph 6.1 gives a view of a number of important permits that are needed, based on laws and regulations that are in place. It also provides a view of the experience with these laws and regulations in Dutch CCS projects that are in the stage of implementation or (firm) planning. Paragraph 6.2 focuses on recommendations how to improve the permitting process in the Netherlands.

5.1 Permits needed for CCS projects

At least ten Dutch acts and regulations are deemed to be relevant for CCS projects. Table 6.1 provides an overview of important permits needed for CCS projects. It is noted that these laws and regulations included in the questionnaire have been considered by the respondents. They (the stakeholders) have also been interviewed. Table 6.1 may be incomplete, as some operators may not have a complete picture. A number of projects still have to apply for permits. Therefore, operators may not be aware of all regulations that are applicable.

A short explanation of the acts and regulations that may be applicable appears to be beneficial:

- The Act on Environmental Management is generally applicable, except in case of offshore CO_2 storage.
- The Mining Law applies to CO_2 storage, which is why it is mentioned by all (future) operators of CCS projects.
- The Act on Spatial Planning applies to the built environment; some projects involve CO_2 capture and storage on an industrial site or offshore CO_2 storage (not applicable).
- The Act on Management of State Hydraulic Works refers to crossing of dikes or dunes.
- The Act on Nature Protection applies if the (CO_2 capture) project is to be realised in the neighbourhood of a nature reserve.
- The Flora and Fauna dispensation may also apply in case the project is in the vicinity of a nature reserve.
- The National Coordination Regulation is meant to shorten the procedures for permits; only relatively large projects (with a national significance) may apply for this regulation, which is why small projects do not qualify.
- A Construction permit is needed for a CO_2 capture plant and for a CO_2 transport pipeline. The law may apply for a CO_2 storage facility if it is onshore.
- The Circular on Transport of Hazardous Substances is mentioned only in three out of nine CCS projects, which may be explained by the fact that some projects have not yet applied for permits.
- The Decision on External Safety of Installations is mentioned in all but two cases; possibly the decision applies to all the projects investigated (sometimes it already applies to an existing activity).

In the following, the laws and regulations are considered in more detail from the point of view of the stakeholders, the (future) operators of CCS projects (or part of CCS chains). Therefore, additional information from the respondents of the questionnaire and the outcome of the follow-up interviews with the stakeholders have been collected in the Tables 6.2 and 6.3. Table 6.2 provides an overview of the length of a permit procedure according to the interviewees of the CCS projects. Interviewees '5' and '9' did not respond to the questions addressed here. With regard to the length of the various permitting procedures, the following observation may be made: respondents '1' and '6' give generic answers of 2-3 years for all permits that are applicable to their projects. However, it appears that they refer to the total length of the permitting procedure, as other respondents show that permits may have a much shorter length. Another way to analyse the experience with permits for CCS projects is to ask interviewees to qualify their experience with specific laws or regulations. In Table 6.3, the experiences have been qualified as 'good', 'not good and not bad' or (possibly) 'bad'.

Table 6.1 ***Permits needed for CCS projects***

	1	2	3	4	5	6	7	8	9
Act on Environmental Management	X	X		X	X	X	X	(X)	X
Mining Law	X	X	X	X	X	X	X	X	X
Act on Spatial Planning	X	X	X	X	X		X		X
Act on Management of State Hydraulic Works	X		X		X		X		
Act on Nature Protection				X	X		X		X
Flora and Fauna dispensation				X	X		X		X
National Coordination Regulation		X			X		X	X	
Construction permit	X	X	X	X	X	X	X	X	X
Circular on Transport of Hazardous Substances	X					X		X	
Decision on External Safety of Installations	X	X			X	X	X	X	X

Table 6.2 ***Length of permitting procedures [years]***

	1	2	3	4	5	6	7	8	9
Act on Environmental Management	2 – 3		2 – 3			2 – 3	< 1	1 – 2	
Mining Law	2 – 3	1 – 2	1 – 2	< 1		2 – 3	< 1	1 – 2	
Act on Spatial Planning	2 – 3	1 – 2	1 – 2			2 – 3	1 – 2	1 – 2	
Act on Management of State Hydraulic Works	2 – 3	1 – 2				2 – 3			
Act on Nature Protection	2 – 3		1 – 2				< 1		
Flora and Fauna dispensation	2 – 3		1 – 2			2 – 3	< 1		
National Coordination Regulation	2 – 3			< 1		2 – 3		1 – 2	
Construction permit	2 – 3	< 1	1 – 2	< 1			< 1	1 – 2	
Circular on Transport of Hazardous Substances				< 1		2 – 3			
Decision on External Safety of Installations	2 – 3			< 1			1 – 2	1 – 2	

Table 6.3 ***Experience with permitting procedures***

	Good	Not good, not bad	Bad
Act on Environmental Management		3	1
Mining Law	3	4	
Act on Spatial Planning	1	4	
Act on Management of State Hydraulic Works		2	
Act on Nature Protection		2	1
Flora and Fauna dispensation		3	
National Coordination Regulation		4	
Construction permit	4	3	
Circular on Transport of Hazardous Substances	2		
Decision on External Safety of Installations	2	3	

5.1.1 Act on Environmental Management

The Act on Environmental Management (Wet Milieubeheer) is generally applicable, except in case of offshore CO_2 storage. More specifically, an offshore installation for storage of CO_2 which is situated beyond the Dutch territorial sea (12 miles zone) does not require an environmental permit under the Act on Environmental Management (Koornneef *et al*, 2008). The act is mentioned by all respondents in Table 6.1 except operator ‘3’, as this is a CO_2 storage project on the Dutch continental shelf (as part of a wider CCS chain). In the ‘Barendrecht’ project, the act is probably applicable to CO_2 transport as it is also applicable to gas transport. The length of the procedure in the framework of this act may be 1 – 2 or less than 1 year (Table 6.2). Probably, 2 – 3 years is not representative.

Table 6.3 shows that the experience with the Act on Environmental Management is perceived as not good and not bad, except in one case (bad experience). Probably, the average perception as ‘not good and not bad’ has to do with the fact that the length is 1 – 2 or (at best) less than 1 year. Maybe, the moderate experience with the act reflects the fact that applying for a permit in the framework of the Act on Environmental Management is time consuming and therefore lengthy.

5.1.2 Mining Law

The Mining Law (Mijnbouwwet) is applicable to CO_2 storage, both onshore and offshore. Therefore the Mining Law is part and parcel of the permitting procedures of the CCS projects involved. The length of the procedure appears to be 1 – 2 or less than 1 year (Table 6.2).

Table 6.3 shows that the experience with Mining Law is perceived as good (3) or not good and not bad (4), which seems to be better than for almost all other acts or regulations.

5.1.3 Act on Spatial Planning

The Act on Spatial Planning (Wet Ruimtelijke Ordening) regulates all CCS activities onshore that are related to the built environment, therefore onshore CCS activities in industrial areas or offshore activities (CO_2 transport and storage) are excluded. Getting a permit in the framework of the Act on Spatial Planning may require 1 – 2 years.

Table 6.3 shows that the experience with Act on Spatial Planning is perceived as not good and not bad, which is reasonable considering that only the Mining Law and the Construction permit, next to regulations on transport of hazardous substances and external safety (the last ones) show better perceptions. The Act on Spatial Planning appears to be well-prepared to include CCS projects.

5.1.4 Act on Management of State Hydraulic Works

The Act on Management of State Hydraulic Works (Wet Beheer Rijkswaterstaatswerken) pertains to parts of the CCS chain that involve intersecting of dunes, dikes, etc. Therefore, the act may apply to onshore and offshore CO_2 pipelines. This act appears to be applicable to four projects. The limited experience (up to now) indicates that the length of the procedure is estimated at 1 – 2 years (Table 6.2) and that the experience is perceived as not good and not bad.

5.1.5 Act on Nature Protection

The Act on Nature Protection (Natuurbeschermingswet) appears to apply to four CCS projects. This may be explained by the fact that some projects (notably the 'Barendrecht' project) involve CO_2 transport and storage in industrial or urban areas, to which the Act on Nature Protection is not applicable. Exceptions are CCS projects that are located at the Eemshaven, bordering the Waddenzee, or a CO_2 pipeline that may be in the neighbourhood of a nature reserve.

Table 6.2 shows that the length of the procedure in the Act on Nature Protection is 1 – 2 or less than 1 year. This may appear to be satisfactory, but Table 6.3 shows that the experience with the Act on Nature Protection is perceived as not good and not bad, except in one case (bad). Possibly, the Act on Nature Protection is not yet well-prepared to deal with CCS projects.

5.1.6 Flora and Fauna Law

The Flora and Fauna Law (Flora- en Faunawet) only applies to those projects that are in the vicinity of nature reserves such as the Waddenzee, or if a CO_2 pipeline intersects an area that has a nature function. The Flora and Fauna Law is always mentioned if the CCS project has to apply for a permit in the framework of the Act on Nature Protection.

The length of the procedure is estimated at 1 – 2 or less than 1 year (satisfactory). The length is perceived as not good and not bad: favourable compared to the Act on Nature Protection.

5.1.7 National Coordination Regulation

The National Coordination Regulation (Rijkscoördinatie regeling) only applies to large CCS projects - for instance demonstration CCS projects - that have a national significance. Therefore, this regulation does not apply to all CCS projects. The law is meant to streamline the permitting procedure of different laws and regulations, as it has an "umbrella function", e.g. there is only one hearing in which the general public may ask questions and raise objections. An operator may apply for this regulation if the CCS project is of national significance, but it is not required.

Table 6.2 shows that the permitting procedure requires 1 – 2 or less than 1 year. Also, Table 6.3 shows that the experience is generally perceived as not good and not bad. As this regulation has only recently been put in place, it may be a bit early to judge whether this is satisfactory or not.

5.1.8 Construction permit

A construction permit (Bouwvergunning) is required for all CCS projects. The length of the procedure is 1 – 2 or less than 1 year. The experience is perceived as good (4) or not good and not bad (3). In this regard, the permit compares favourably to a number of other permits.

5.1.9 Circular on Transport of Hazardous Substances

The Circular on Transport of Hazardous Substances (Circulaire Risiconormering Vervoer Gevaarlijke Stoffen) appears to be applicable to only three CCS projects (unless some operators are not aware of the circular). Taking into account this small number, it appears to be satisfactory that the procedure is estimated at less than 1 year. Also, Table 6.3 shows that the experience with the circular is generally perceived as good (2).

5.1.10 Decision on External Safety of Installations

The Decision on External Safety of Installations (Besluit Externe Veiligheid Inrichtingen) appears to be generally applicable to CCS projects, except (probably) the part of the chain corresponding to offshore CO_2 storage (which is covered by the Mining Law). Table 6.2 indicates the length of the procedure is 1 – 2 years or less than 1 year. The experience with the regulation is satisfactory: varying from good to ‘not good and not bad’, comparable to the Mining Law.

5.2 Conclusions and recommendations

At least ten Dutch acts and regulations are deemed to be relevant for CCS projects. Based on the responses to the questionnaire, the total length of the permitting procedure seems to be between 2 to 3 years. As a number of interviewees (operators of CCS projects or parts of the chain of a CCS project) pledge for an ‘encompassing package covering CCS activities with a strong involvement of the government’, it is highly important that the authorities involved (government and/or province or municipality) realise that a strong involvement with facilitating of CCS projects does not allow unnecessarily lengthy permitting procedures. There have been unsatisfactory experiences with the permitting of the first few CCS projects. However, this was generally not due to specific laws or regulations but due to conflicting views on the requirements for CSS at different levels. This in itself makes the proposed ‘packaging’ an option to be seriously studied.

Furthermore, Appendix D provides a long list of acts and regulations that are reported for a few CCS projects that are relatively advanced in terms of permitting procedures.

6 Environmental Impact Assessment

6.1 Overall results questionnaire

In Table 7.1 an overview is given of the answers on the questionnaire. It is indicated whether a question is answered with yes, no, additional information is given, or no answer has been given.

The table shows that almost all questions have been answered by the respondents. The only clear exception is question V68 on the effect of the use of different types of solvents. This question is only relevant for the sites including carbon capture technology. Question V67 indicates that only two respondents reply that solvent flexibility is an option.

Not all respondents did answer the questions at the same level of detail, but often the answers included valuable additional information. In the following paragraphs the answers are discussed in more detail by the following different themes: Environmental Impact Assessment (EIA), Environmental data availability, Life Cycle Analysis (LCA), Cost-Benefit Analysis (CBA), Measurements of environmental data and Respondents' opinion on environmental issues.

Table 7.1 ***Overview of answers on questionnaire (0 = No, 1 = Yes, X = additional information, blank = no answer)***

	Respondent	1	2	3	4	5	6	7	8	9
	Environmental Impact Assessment (EIA)									
V46	Is an EIA (Environmental Impact Assessment / MER) already available?	0	0	0	0	1-X	0	0	1	0
V47	Please upload the EIA to the CATO-2 site and continue with the next question.									
V48	At what date is an EIA needed?	X	X	X	X	X	X	X		X
V49	Who will perform this EIA (if known)?	X	X	X	X	X	X	X		X
V50	How do you define the 'zero alternative'?	X		X	X	X	X	X		X
V51	How do you define 'other alternatives'?	X		X	X			X		0
V52	How do you define 'most environmentally friendly alternative'?	X		X	X			X		X
	Environmental data availability									
V53	What environmental data are available for EIA?	X	X	X	X			X		X
V54	Are there any data missing?	0	1	0	1		0	1		1
	Life Cycle Analysis (LCA)									
V55	Do you consider life cycle data (cradle-to-grave) as relevant?	0	1	1	1		0	1		0
V56	Are these life cycle data available today?	0	0	0	1		0	0		0
V57	What temporary impacts do you expect during construction?	X	X	X	X		X	X		X
V58	How do you calculate cumulative impacts from other industries?	X		X	X			X		X
V59	How do you assess following impacts?									
	Cost-Benefit Analysis (CBA)									
V60	Did you perform a cost-benefit analysis?	1	1	1	1		0-X	0		1
V61	How was the cost-benefit analysis performed?	X		X	X					X
V62	What were the main assumptions?	X		X	X					
	Measurements of environmental data									
V63	Do you have in particular data on:	X	X	X	X	X	X	X	X	X
V64	Will the CCS installation be operated continually or is flexible operation allowed?	X	X	X	X		X	X	X	X
V65	How does this impact the emissions?	X		X	X			X	X	X
V66	How flexible is the capture installation for the use of different types of solvents?		X		X	X	X	X	X	
V67	Does flexibility with regard to solvents used impact the design and operation of the facility? What is the impact of the flexible solvents regarding the design and operation of the facility?		1		0		0	1	0	
V68	What is the impact of the flexible solvents regarding the design and operation of the facility?							X		
V69	What environmental data is planned to be measured at the site?	X	X	X	X			X	X	X
V70	What method (sampling / continuously) and measuring instrument are used?	X		X	X			X	X	X
V71	Who will perform the measurement (internal / external)?	X	X	X	X		X	X	X	X
V72	In what form (unit, time series, etc. Think of kg/year, kg/hour, mg/m3, kg/kWh, kg/PJ) is environmental data most useful for you? Please explain.	X	X	X	X			X	X	X
	Respondents' opinion on environmental issues									
V73	On what topics is environmental data most useful for you?		X	X	X			X		
V74	Are there any other topics on which environmental data is most useful for you?	X		X	X			X	X	
V75	What would a 'Best Practice' for monitoring look like (see also heading 'Monitoring')?	X		X	X			X	X	

6.2 Environmental Impact Assessment

For only one out of the nine projects an Environmental Impact Assessment (EIA) is available. A second project has an EIA for only a part of the process, which is not directly related to CCS. Two locations need an EIA in 2010, 5 others need the EIA later. It still has to be decided who will carry out the EIA; two respondents indicate that it will be done by a consultant. The “zero alternative”, “other alternatives” and “the most environmentally friendly alternative” are alternatives for the CCS project, which have to be described in the EIA. They have still to be defined for most of the projects. Two respondents indicate as the “zero alternative” a process without CCS, where CO_2 is released to the air. As an alternative another storage location could be applied according to one of the respondents.

6.3 Data availability

The available data for an EIA is limited according to respondents. They referred to the AMESCO study, older data from off shore reservoirs, questions asked to suppliers, studies in- and outside CATO or they state that mainly capture related emissions are available. Four respondents replied that there are data missing for an EIA, three respondents answered that no data are missing.

The temporary impacts during construction are expected to be limited. Only noise and traffic are mentioned by a number of respondents. How the cumulative impacts from other industries should be calculated is unknown to the respondents.

The respondents do not have any particular data on emissions, or (toxic) waste.

6.4 Life Cycle Analysis

Next to the environmental impacts of the CCS project itself, the impacts over the life cycle of CCS could be taken into account. An example of an indirect part of the chain is the mining and transportation of coal for the power generation in the power plants. But also, the production of technology and other products used for CCS are covered in a full Life Cycle Analysis (LCA). About half of the respondents indicate that LCA data are considered as relevant. Except for one respondent, the respondents think these data are not available yet (to them).

6.5 Cost - Benefit Analysis

Most of the respondents answered that they did perform a Cost Benefit Analysis (CBA). One respondent performed a confidential business case including ETS CO_2 price and subsidies, but without soft data (social costs). It is indicated by another respondent that the foundation CCS NL intends to make a social cost benefit analysis. The outcome of a CBA of a third respondent was negative, the costs are higher than the benefits. The process is inefficient, but the main goal is to learn from the project.

No details on how the CBA was performed are given. Respondents answer that it is confidential, or that they use economic modelling or that they estimate the costs and benefits with current available information (POT and IRR calculations were performed).

Hardly any details on the assumptions for the CBA are given. One respondent answered that they calculated with a governmental funding, a CO_2 price of 20 Euro/tonne and an investment cost calculation on conceptual engineering package.

6.6 Measurements of environmental data

Not all respondents do already know what measurements will be performed. Of course it depends on the project (capture or storage). One respondent indicated that emissions to air and water will be measured (NOx, CO and CxHy). Another mentioned emissions to water and some indicated that CO_2 emissions will be measured/monitored. How and by whom the measurements will be performed has in general not been decided yet. Some indicate that it will be done internally or by external partners. One respondent answered in more detail, an external partner was mentioned as well as the following measurements: Flow measurements, pH analysis of the groundwater and pressure measurements in the underground.

6.7 Respondents opinion

Most respondents indicate that environment is considered to be a relevant issue. Especially the capture plants are interested in the environmental data on NO_x, PM, amine emissions and amine degradation products, heavy metals and solvent waste. Also, it is indicated that a tool to support Environmental Impact Assessment is considered very useful.

6.8 Conclusions and recommendations

The results of the questionnaire indicated the following:

- Not all respondents did answer the questions at the same level of detail, but often the answers included additional information which is very valuable.
- For only one of the projects an EIA is available. The other projects plan to perform the EIA in 2010 or later.
- The available data for an EIA is limited, the location managers refer to other studies, but half of the respondents indicate that data are still missing.
- Not all respondents already know which measurements will be performed in the project.
- Half of the respondents consider LCA data as relevant. Most of the respondents indicate that these data are not available.
- Most of the respondents indicated that they performed a CBA, however, these included only costs and benefits to the company and not costs and damages to society, the so-called external effects. In fact, it concerns not so much a CBA, but a profitability analysis.

From these observations, we conclude that the non-CO_2 environmental impacts are considered relevant, however, are not yet in the picture as a major CCS issue or acceptance risk in the early stages where current CCS pilot projects are in. This assessment is primarily based upon the current properties of power generation technology, the general working mechanisms of CCS technologies and international literature. Nevertheless, information and support in the assessment of non-CO_2 environmental impacts over the full life cycle are welcomed.

7 Underground storage

7.1 Introduction

The goal of the underground storage questions was to obtain knowledge on:

- risk assessment procedures currently used/performed;
- monitoring procedures stated in the monitoring plan;
- preventive and corrective measures defined.

The results provide insight into the phase of the project, the procedures currently used and the requirements and needs of the location managers.

In total 9 respondents completed the questionnaire. All respondents stated that the projects mentioned concern storage operations. However only 4 from the 9 respondents are storage operators. Five respondents are capture operators. However, they also completed the storage part of the questionnaire using obtained knowledge from the storage operator. Their answers are equally used in the evaluation of the questionnaire.

In Table 8.1 an overview is provided of the questions concerning underground storage (V88 – V120) as well as given answers and if further information is provided.

Table 8.1 ***Overview response concerning underground storage questions (0 = no answer is given, 1 = an answer is given, x = an explanation is given***

	CCS initiatives	1	2	3	4	5	6	7	8	9
V88	In which phase of the lifecycle is your storage project?	1	1	1	1	1	1-x	1	1	1
V89	Did you or do you pre-select and prepare a list of potential storage options and ranked them according to their suitability for safe and effective storage?	1	0	X	x	x	1	1	0	0
V90	Which potential storage sites have been pre-selected?	0	0	0	0	0	1	1	0	0
V91	What are the main characteristics of the pre-selected sites (aquifer, gas field or oil field, type of seal, type of reservoir, presence of faults and wells)?	0	0	1	x	0	1	1	0	x
V92	Which ranking criteria were or are used and what is the outcome of the ranking exercise?	0	0	0	0	0	1-x	1	0-x	0
V93	Is all existing data relevant to the CO_2 containment and risk assessment readily available for your company?	1	1	1	1	1-x	1-x	1	1	x
V94	What existing data is available from earlier hydrocarbon exploitation or other subsurface activities?	0	0	1	1	0	0	0	1	0
V95	Did you or do you need to acquire additional data for the proper assessment of CO_2 containment and risks of CO_2 storage?	1	1	1	1	1-x	1-x	1	1	0-x
V96	What additional data is acquired to formulate a hypothesis on cap rock/fault/reservoir/well behaviour? (please describe in very concise terms)	0	0	0	1	0	1	1	0	0
V97	How is information managed so that it can be used to support the performance assessment?	0	0	0	1	0	0	1	0	0
V98	Did you or do you perform an assessment of CO_2 containment and risk related to CO_2 storage?	1	1	0	1	1	1-x	1	1-x	0
V99	Is the concept of CO_2 containment clearly defined as well as the objective of the assessment and the setting of the site?	0	0	0	1	1	1	0	1	0
V100	Have you identified non-integrity/leakage scenarios and if yes, which?	0	0	1	1-x	1	1	0	1	x

V101	Is there a need for quantitative assessment of risks mentioned in the preceding question?	0	0	0	1	1	1	0	1	0
V102	How do you estimate maximum pressure and capacity and how confident are you that predicted pressure range is not exceeded?	0	0	1	1	1	1	0	1	0
V103	How do you demonstrate confidence in your understanding of the likely lateral extent of the storage system with time?	0	0	0	1	1	0	0	1	0
V104	Did your performance assessment result in possible recommendations for additional site characterisation activities and if yes, which?	0	0	1	1	1	0	0	0	0
V105	Did you or do you develop a monitoring plan to confirm CO_2 containment and to identify irregularities related to CO_2 storage?	1	1	1	1-x	1-x	1	1	1-x	0
V106	Which tools did you select for monitoring containment and irregularities and why?	0	0	0	1	1-x	0	1	1-x	0
V107	Is your monitoring plan compliant with the EU Storage Directive? If not, what additional monitoring would be required?	0	0	1	1-x	1	0	1	1	0
V108	Did you adjust your original monitoring plan during operation?	0	0	0	0-x	0	0	0	0-x	0
V109	Did you or do you develop a plan including preventive and corrective measures?	1	1	0	1	1-x	1	1	1-x	0
V110	Has the engineering design (no of wells, pressure) been adapted to minimize risks?	0	0	0	1	0	0	1	1	0
V111	How has the engineering design mentioned above been accomplished?	0	0	0	1	0	0	1	1	0
V112	Are there existing wells which need a workover as to minimize well leakage risks?	0	0	0	1	0	0	1	1-x	0
V113	Which workover activities have been proposed/were executed?	0	0	0	0	0	0	1	1	0-x
V114	Which potential corrective measures have been identified?	0	0	0	1	0	0	0	0	0
V115	Is a plan for abandoning the wells in place as well as a plan for long-term monitoring and site maintenance?	1	1	0	1	1-x	1	1	1	0
V116	Have the results of the assessment been integrated with the monitoring plan and the plan with preventive and corrective measures?	1	1	0	1	1	1	1	1	0
V117	Did you or do you develop a risk register (table with identified risks, monitoring plan and preventive and corrective measures)?	0	0		1	0	0	0	1	0
V118	Do you use monitoring data to test your predictive reservoir model for the long-term performance of the storage site?	0	0	0	1	0	0	0	1	0
V119	Is a system for verification, reporting and updating in place?	0	0	0	1	0	0	0	1	0
V120	On the basis of which performance criteria do you conclude that the site is performing in a safe and effective way on the long term?	0	0	1	1	0	0	0	1	0

The main part of the underground storage section of the questionnaire contained open questions. The results are presented in a description.

7.2 Phase of the storage project

The results of the underground storage part of the questionnaire are based on the phase of the storage life cycle of the projects. In some projects extensive knowledge is present, others have to start gathering the information. None of the storage projects advanced beyond the site qualification phase towards the injection, closure or post-closure. As shown in Figure 8.1 most of the projects are in the pre-selection or in the site qualification phase, prior to the permit application.

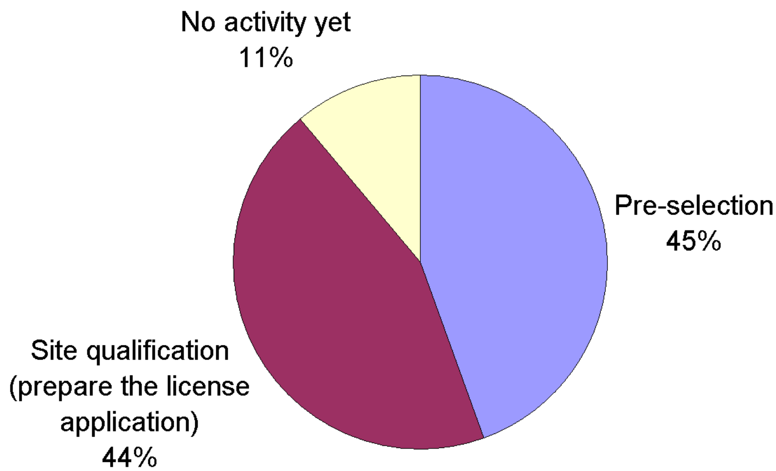

Figure 8.1 ***Distribution of phases of the storage projects. None of the storage projects are in the operation, closure or post-closure phase***

The last part of the questionnaire (Q 105 - 120) deals with the status of the project and requires answers in relation to operational and post-operational phases. Due to the fact that several of these procedures and processes are executed in a later phase of the project the number of answers from the respondents decreases towards the end of the questionnaire.

Currently there is uncertainty on the decisions to be made by the Dutch government, especially on financial support for the pilot and demonstration projects concerning CO_2 storage. This is seen as the most important influencing factor for the current progress of the projects. Many respondents state that large efforts have been put into the first stages of the current projects but many, if not all, projects are currently put on hold, awaiting a positive decision from the Dutch government.

7.3 Selection of the storage site

The respondents that stated the pre-selection phase for their projects also answered questions on the pre-selection procedures, i.e. pre-selection choices, main characteristics of the pre-selected sites, and ranking criteria used.

The pre-selection and preparation of a list of potential storage options and the ranking according to their suitability for safe and effective storage appears to be mainly based on the availability of storage sites. In some cases multiple storage sites have been identified. In others, when only one possibly suitable storage site near or under the premises of the capture plant can be identified, a pre-selection procedure with multiple storage options is not performed. It appears that availability of reservoirs nearby or directly available underneath the premises is the most important ranking criterion. These reservoirs are preferred and will be one of the firsts to enter the selection process, if more than one reservoir is investigated. Other criteria mentioned for the ranking of the storage sites are (in random order): capacity, availability infrastructure, wells, conversion costs, feasibility, injectivity, (safe) containment, and whether the storage site meets the preconditions stated in the tender published by the Dutch government.

The questions regarding the main characteristics of the pre-selected sites (aquifer, gas field or oil field, type of seal, type of reservoir, presence of faults and wells) were in general only answered by type (gas field, aquifer) and in one case no decision has been made yet.

7.4 Data availability and data acquisition

A third of the respondents answered positively to the question whether existing data relevant to the CO_2 containment and risk assessment is readily available to each company. In general data is available in case of a CO_2 storage site with a production history or other subsurface activities. This data concerns e.g. geological maps and mining maps of the location, seismic, well data, production history and ground movement data.

However, due to the fact that not all respondents have a clear view on available data, or for instance presume that the storage operator will have all the data, this result needs to be further investigated. Since the available data originate from previous production activities, it needs to be further elaborated whether this information is sufficient for the proper assessment of CO_2 containment and risks of CO_2 storage. For instance additional exploration drilling could be needed to confirm data available from previous drilling, as well as to obtain new data needed for the design of the CO_2 storage project.

More than half of the respondents indicated that they need to acquire additional data for the proper assessment of CO_2 containment and risks of CO_2 storage. One respondent gave a concise answer on what type of additional data is required to formulate a hypothesis on cap rock, fault, reservoir and well behaviour, i.e. 2D-seismic measurements and core-drilling samples. The remaining respondents did indicate that more data is needed but were not specific or still have to decide which data is missing and needs to be acquired.

7.5 Performance/risk assessment

In half of the storage projects an assessment of CO_2 containment and risks related to CO_2 storage has not yet been performed (for the identification of non-integrity leakage scenario's, determination of maximum pressure, capacity, likely lateral extent of the storage system in time). For the storage projects that did perform an assessment several methods were mentioned. As standard assessment criteria have not been defined to date, the methods used differ among the storage projects. Besides this, knowledge on risk assessment methods is not always available among the respondents as this assessment is performed by the storage operator.

In literature various leakage scenarios are defined, which were evaluated for one of the storage projects. In this case leakage along a fracture is assumed to be the most relevant. However, it needs to be determined whether a fault is present in the layers above the reservoir. Another respondent mentioned scenarios that were defined in the eighties, with the knowledge and laws of those days, and that this research needs to be evaluated for the current project (CO_2, current laws, current knowledge on materials). In one storage project all scenarios have been defined. In order to evaluate the risks a quantitative assessment can be performed. However, it was mentioned that there is not always a need for a quantitative assessment among the storage projects.

Different options used for estimating maximum pressure and capacity were presented, i.e. geological data in combination with models, dynamic modelling by history matched Mores Model, static head of water column. One of the respondents stated that the models used will be checked during a pilot project before large-scale storage will be applied.

The reactions obtained for methods used to demonstrate confidence in the understanding of the likely lateral extent of the storage system resulted in the following methods:

- geological data in combination with models;
- static and dynamic GIIP (Gas Initially in Place) from production;
- the assumption that CO_2 is laterally distributed across the entire well known reservoirs.

7.6 Monitoring

In approximately half of the projects a monitoring plan is available. However, when asked for further description of the monitoring tools and plans it appears that in two cases the choice of monitoring tools has not yet been decided. Examples of tools described by one of the respondents are seismic research, pressure measurements, pH measurements, CO_2 analyses of groundwater samples, CO_2 analyses of mine water, pressure techniques to show fractures and ground movement. Also, it was stated that in another case the well integrity is the most important factor and needs to be monitored. Measurement tools are therefore based on the risk of well leakage. Especially leakage along the cement plug-casing interface is considered the largest risk.

7.7 Preventive and corrective measures

Probably due to the early stage of the storage projects described in this report a preventive and corrective measures plan was not developed yet in most of these projects. In some cases, however, the plan is available. In several projects the engineering design (number of wells, pressure) was adapted to minimize risks. In one case the conceptual engineering work is ready and the basic and detailed engineering will be done by experienced companies in the field of oil and gas transport, drilling, storage. In two other storage projects a workover is needed for existing wells in order to minimize risks. In one case corrective measures have been identified and concern pressure switch valves in the above ground equipment that can blow off the CO_2 in case of a too high pressure.

7.8 Abandonment

As stated before proceeding to the last questions of the questionnaire and therefore moving towards the later phases of a CO_2 storage project the information available decreases significantly. In some cases a plan for abandoning the wells as well as a long-term monitoring plan and site maintenance is stated to be in place. However, many respondents stated not to have this plan available.

7.9 Risk management

Especially the questions related to risk management were answered by only some of the respondents. As stated in the previous section this could be due to the phases of the projects. In two cases the results of the assessment have been integrated with the monitoring plan and the plan with preventive and corrective measures. Also, a risk register (table with identified risks, monitoring plan and preventive and corrective measures) was developed in two cases. Moreover, monitoring data was used to test the predictive reservoir model for the long-term performance of the storage site. In one case a system for verification, reporting and updating is in place. Performance criteria in order to conclude that the site is performing in a safe and effective way on the long term is described in one case in their EIA.

7.10 Conclusions and recommendations

Based on the results of the questionnaire it appears that standard procedures and processes for risk management are currently not available in relation to underground storage issues. This is probably due to the early stage of preparation of storage operations. None of the projects have started to operate and therefore knowledge on the procedures and processes, which will be tested during operation, is not yet available. Therefore, mostly general risk assessments have been performed and monitoring plans, abandonment plans and preventive and corrective measures are described in non-specific manners, if available.

New questions were derived based on the results of the current questionnaire used in this project. These questions concern the risk assessment procedure, preventive and corrective measures and risk management procedures for underground storage. These questions could give more insight into the current gaps that are present in underground storage risk management procedures and processes.

Risk assessment

- How do you determine which data is relevant to the CO_2 containment and risk assessment ?
- How do you perform an assessment of CO_2 containment and risk related to CO_2 storage for your specific site?

Preventive and corrective measures

- How do you determine preventive and corrective measures to ensure long-term CO_2 containment?

Risk management

- How do you determine which monitoring tools can confirm CO_2 containment and identify irregularities related to CO_2 storage?

General

- What are the priorities of location managers?

8 Monitoring of emissions for the EU ETS

8.1 General

Monitoring of the CO_2 emissions, in all parts of the CCS chain, is necessary to asses whether identified leakages are harmful for human health, or damage the environment. According to EC Directive on the geological storage of carbon dioxide (2009/31/EC), the surrounding environment should be monitored for the purpose of "…detecting significant adverse effects for the surrounding environment , including in particular effects on drinking water, for human populations, or for users of the surrounding biosphere".

An entirely different reason for monitoring is the monitoring of the CO_2 stream/storage for the EU ETS. During the operation phase monitoring is required for the quantification of the:

- amount of captured and transferred CO_2 into the transport system;
- CO_2 leakages during transport and injection into an underground storage.

After the CO_2 injection has ceased and the storage site has been abandoned, monitoring aims at the stored CO_2 verifying whether the injected CO_2 is permanently stored and if not, to calculate the CO_2 leakage from the storage.

The questions in the questionnaire were focussed on monitoring related to EU ETS. Due to the early stage of most of the CCS initiatives the response was rather poor. See Table 9.1 for an overview. The results are discussed in the next sections

Table 9.1 ***Overview response (1 = answered with yes, 0 = answered with no, x = some or more explanation is given)***

Question	CCS Initiatives	1	2	3	4	5	6	7	8	9
v76	Is there a monitoring system designed that is relevant for the EU ETS?	1	0	0	1-x	0-x	0	1-x	0-x	1-x
v77	Is there a concept monitoring plan for the project for monitoring under EU ETS?	0		0	1-x			1-x		0
v78	Has the measurement uncertainty of the monitoring system been evaluated?				1-x			1-x		x
v79	Describe the monitoring system for emissions under the EU ETS				x			x		
v80	Which types of monitoring systems are evaluated for the monitoring of the storage site?				x			x		
v81	Which criteria have been evaluated on the monitoring systems for the storage site?				x			x		
v82	What is the chosen quantification method for emission reported for the EU ETS?							x		
v83	What is the composition of the CO_2 stream?			x	x	x	x	x		x
v84	What are the composition ranges of the CO_2 stream?							x		
v85	Is the mass of CO_2 transported from source to the well determined by mass balance or retention rate?				x			x		
v86	Is verification of the monitoring system evaluated in the choice for a measurement system?									
v87	How is the quality of the measurement ensured (EN 14181 considered in the evaluation)?									
v121	Is there data on measurement of CO_2 and measurement uncertainty?	0	1		1	0	0	1	0	0
e10b	What are the physical conditions (pressure, temperature) of the measured CO_2-stream?			x		x	x	x	x	x
e10c	Have concrete/specific choices been made for measuring equipment?					0	0	x	0	

8.2 Discussion of the results with regard to monitoring

8.2.1 Monitoring Plan

In most of the cases a monitoring system for the CCS activity, as part of the EIA, is already designed or is in preparation. In some cases reference is made to the monitoring plan for the CO_2 emissions under EU ETS. These existing monitoring plans must be adapted for the CCS activity. The requirements for a monitoring plan for CCS are either not clear, or the question is how to translate them into a monitoring plan.

8.2.2 Measurements uncertainty

As can be seen in Table 8.1 the response on the question about the measurements uncertainty was rather low. Those who evaluated the uncertainty are aware that a good measuring method needs to be in place. Some indicate that in cases of liquid CO_2 streams an uncertainty of 1% or even 0.5% must be manageable.

There was no response on the question about quality assurance of the measurements. Only in three cases there is data available about CO_2 measurements and measurement uncertainties.

8.2.3 Monitoring methodology

In general the amount of CO_2 produced, is based on the measurement of the fuel consumption. As far as the projects have responded, the amount of transported and stored CO_2 is based on flow measurements. The calculation of the amount of CO_2 from source to well will be determined by mass balance.

For the selection of monitoring systems accuracy is the most important criterion.

8.2.4 Composition of the CO_2-stream

In most of the cases the CO_2 stream consists for 99%-100% of CO_2, in one case "mainly CO_2" was mentioned. In some cases the CO_2 purity is not clear yet; it depends on the outcome of process optimisation experiments. It can also depend on requirements for the transport and storage system. When the CO_2 is a by-product from ammonia production, the major impurities are hydrogen and nitrogen (together about 0.5%), while the other components (such as SO_2, NO_x , NH_3 , etc) are in general < 1 ppm.

In all cases the CO_2 stream needs to be dry to avoid corrosion in the compression, transport or injection system.

The effects of impurities are still not clear and need to be investigated.

8.2.5 Physical conditions of the CO_2 stream

The physical conditions of the CO_2 stream for each project are very different. For three cases the conditions are given in Table 9.2.

Table 9.2 ***Physical conditions of CO_2 stream***

Project	Pressure	Temperature
1	100 bar	100 °C
2	max. 80 bar	
3	few bars	40-50 °C

For those projects that are in an early stage of development the physical conditions are not always clear, and have to be researched first. It depends for instance on the amount of CO_2 captured, distance to the storage and the conditions in the storage.

8.2.6 Verification of CO_2 emission report

The purpose of monitoring of the CO_2 stream and CO_2 storage is to provide an annual emission report that is consistent, transparent, accurate and also verifiable.

On the question about the role of verification in the choice for measurement systems and on the quality assurance of the measurements not response has been received. It seems that at the current stage of the projects not much attention has been given to these items yet.

8.2.7 Measuring equipment

Based on the responses one can draw the conclusion that it is very well known which parameters should be measured and what kind of equipment is needed (seismics, pH, gas analyser, CO_2 flow, pressure and temperature above- and underground, soil movement, CO_2 sensors, etc), but in general no choices are made for specific measuring equipment. And although for one project a detailed monitoring plan is available, in which a list is given of relevant parameters and measuring methods, there is no information about which measuring equipment will be used.

For some projects the captured CO_2 will be transferred to companies engaged in transport and storage. In those cases these companies prescribe the physical conditions of the CO_2 stream and subsequently also determine the way of monitoring.

8.3 Conclusions and recommendations

The general impression is that for most of the projects monitoring for EU ETS is not an important issue yet. Not only because of the stage of the project, but in some cases also because they don't feel responsible for it and leave this to the companies who will transport and store the CO_2.

There is some concern about the effect of a too comprehensive monitoring programme. Implementation of monitoring systems for all imaginable parameters could suggest that processes are not completely understood. And lay people could easily draw the conclusion that when measurements take place, there also something will be measured (think of CO_2 seepage to the surface). Measurements should take place only when it makes sense.

A template of a generic monitoring plan would be very welcome.

9 Conclusions and recommendations

The results of the questionnaire and the subsequent interviews with the location managers of the CCS projects considered, have led to some conclusions and recommendations, as presented below.

General aspects location

All the projects considered are still in the development phase and none are operational yet. The capture technologies of the CCS projects considered are *post-combustion*, *pre-combustion*, and *oxy-fuel*. In addition, in two of the concerned CCS projects the CO_2 is a 100% pure stream. In most of the considered CCS projects, the transport of CO_2 from the capture site to the storage site will take place through newly built pipelines. The majority of the storage sites in the projects considered are related to natural gas production, one site is also related to oil production. None of the natural gas or oil production sites are abandoned yet. In addition, two aquifers are also selected for CO_2 storage.

Permitting of CO_2 capture and storage projects

At least ten Dutch acts and regulations are deemed to be relevant for CCS projects. Based on the responses to the questionnaire, the total length of the permitting procedure seems to be between 2 to 3 years. As a number of interviewees (operators of CCS projects or parts of the chain of a CCS project) pledge for an ‘encompassing package covering CCS activities with a strong involvement of the government’, it is highly important that the authorities involved (government and/or province or municipality) realise that a strong involvement with facilitating of CCS projects does not allow unnecessarily lengthy permitting procedures. There have been unsatisfactory experiences with the permitting of the first few CCS projects. However, this was generally not due to specific laws or regulations but due to conflicting views on the requirements for CSS at different levels. This in itself makes the proposed ‘packaging’ an option to be seriously studied.

Environmental Impact Assessment

From the observations based on results of the questionnaire, it can be concluded that the non-CO_2 environmental impacts are considered relevant, however, are not yet in the picture as a major CCS issue or acceptance risk in the early stages where current CCS pilot projects are in. This assessment is primarily based upon the current properties of power generation technology, the general working mechanisms of CCS technologies and international literature. Nevertheless, information and support in the assessment of non-CO_2 environmental impacts over the full life cycle are welcomed.

Underground storage

Based on the results of the questionnaire it appears that standard procedures and processes for risk management are currently not available in relation to underground storage issues. This is probably due to the early stage of preparation of storage operations. None of the projects have started to operate and therefore knowledge on the procedures and processes, which will be tested during operation, is not yet available. Therefore, mostly general risk assessments have been performed and monitoring plans, abandonment plans and preventive and corrective measures are described in non-specific manners, if available.

Monitoring of emissions for the EU ETS

The general impression is that for most of the projects monitoring for EU ETS is not an important issue yet. Not only because of the stage of the project, but in some cases also because they don't feel responsible for it and leave this to the companies who will transport and store the CO_2.

There is some concern about the effect of a too comprehensive monitoring programme. Implementation of monitoring systems for all imaginable parameters could suggest that processes are not completely understood. And lay people could easily draw the conclusion that when measurements take place, there also something will be measured (think of CO_2 seepage to the surface). Measurements should take place only when it makes sense.

A template of a generic monitoring plan would be very welcome.

10 References

CATO-2 Program Plan, Annex 1: LPDs & WPDs, CATO-2-WP0.A-D03 (restricted), 2010.09.30.

EU (2003): Directive 2003/87/EC of the European Parliament and of the Council of 13 October 2003, *Establishing a scheme for greenhouse gas emission allowance trading within the Community and amending Council Directive 96/61/EC*. European Commission, Brussels, October 13, 2003. http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=CONSLEG:2003L0087:20090625:EN:PDF

NER (Nederlandse Emissie Richtlijn): http://www.infomil.nl/onderwerpen/klimaat-lucht/ner/digitale-ner/.

Koornneef, J.M. *et al* (2008): *The screening and scoping of Environmental Impact Assessment and Strategic Environmental Assessment of carbon dioxide & storage in the Netherlands.* Environmental Impact Assessment Review, 28 (6), 2008, pp. 392-414.

Taqa (2009): *CO_2 Offshore Storage - Deep under the North Sea*. Taqa Energy B.V., The Hague, the Netherlands, 2009. http://www.taqa.ae/assetsmanager/files/pdf/co2.pdf

Appendix A The Questionnaire

1	What is the preferred confidentiality of the answers of this questionnaire?	Vraag (single response)

- ◯ Answers can be published within the CATO-2 community
- ◯ Answers are confidential

2	1. General aspects location Which parts of the CCS chain are represented in your project?	Vinkvraag (multi response)

Minimaal aantal vinkjes: 1

- ☐ Capture
- ☐ Transport
- ☐ Storage

3	What is the name of the CCS project?	Open vraag (klein)

4	Where is the project located?	Open vraag (klein)

5	Is the storage onshore or offshore?	Vraag (single response)

- ◯ Onshore
- ◯ Offshore

6	Is the CCS project in operation?	Vraag (single response)

- ◯ Yes [>> 8. In which year will the project be termin...]
- ◯ No

7	In which year does the project start, i.e. become operational?	Open vraag (klein)

8	In which year will the project be terminated?	Open vraag (klein)

9	Can you provide a short description of operation?	Open vraag (groot)

Vraagvoorwaarde actief Vraag 6.0
(Is the CCS project in operation?)
Antwoord WEL gegeven: **Yes**.
Indien niet voldaan spring naar: 17. What CO_2 capture technology is applicabl...

10	What were the main reasons for the selection of this site?	Open vraag (groot)

11	Were/are there any alternative candidate sites for this CCS project?	Vraag (single response)

- Yes
- No

12	What is the distance between the CO_2 capture installation and the storage operation?	Open vraag (groot)

13	How densely populated is the area?	Vraag (single response)

- Less than ‘average NL’
- ‘Average NL’
- More than ‘average NL’

14	Why did you choose to invest in CCS?	Open vraag (groot)

15	Did you use media to present the operation?	Vraag (single response)

- Yes
- No

16	Which media and in what way?	Open vraag (groot)

Vraagvoorwaarde actief Vraag 15.0
(Did you use media to present the operation?)
Antwoord WEL gegeven: **Yes**.
Indien niet voldaan spring naar: 0. Volgende vraag

17	What CO_2 capture technology is applicable?	Vraag (single response)

Vraagvoorwaarde actief
Vraag 2.0
(1. General aspects location

Which parts of the CCS chain are represented in your project?)
Antwoord WEL gegeven: **Capture**.
Indien niet voldaan spring naar: 23. Which is the way CO_2 is (to be) transpor...

- Post-combustion
- Pre-combustion
- Oxy-fuel

18	How much CO_2 is (to be) produced?	Open vraag (groot)

19	How much CO_2 is (to be) captured?	Open vraag (groot)

20	What is the ratio of production / capture of CO_2?	Open vraag (groot)

21	What is the source of the CO_2?	Vraag (single response)

- Coal-fired power plant
- Gas-fired power plant
- Gas production / processing
- Ammonia production plant
- Oil refinery
- Other

22	Is there room for extension of CO_2 captured?	Vraag (single response)

- No
- Yes, up to 25%
- Yes, between 25 and 50%
- Yes, more than 50%

23	Which is the way CO_2 is (to be) transported?	Vinkvraag (multi response)

Minimaal aantal vinkjes: 0

Vraagvoorwaarde actief	Vraag 2.0 (1. General aspects location Which parts of the CCS chain are represented in your project?) Antwoord WEL gegeven: **Transport**. Indien niet voldaan spring naar: 27. What is potential CO_2 volume of the rese...

- ☐ By ship
- ☐ By existing pipeline
- ☐ By newly built pipeline

24	How much CO_2 is (to be) transported?	Vraag (single response)

- ○ 0-200,000 t CO_2/a
- ○ 200-400,000 t CO_2/a
- ○ 400-600,000 t CO_2/a
- ○ 600-800,000 t CO_2/a
- ○ 800-1,000,000 t CO_2/a
- ○ > 1,000,000 t CO_2/a

25	Which operational transport conditions should be met by the design (pressure, distance, temperature, purity)?	Open vraag (groot)

26	Which design and material specifications will be applied for the defined transport-unit(s) (dimensions, material, lining) ?	Open vraag (groot)

27	What is potential CO_2 volume of the reservoir?	Open vraag (groot)

Vraagvoorwaarde actief	Vraag 2.0 (1. General aspects location Which parts of the CCS chain are represented in your project?) Antwoord WEL gegeven: **Storage**. Indien niet voldaan spring naar: 39. 2. Permit application Which p...

28	What is effective CO_2 capacity of the reservoir?	Open vraag (groot)

29	Are there any (expected) potential conflicts of land use at the ground level of the storage site?	Vraag (single response)

- ○ No

○ Yes

30	Which potential conflicts (to be expected)?	Vinkvraag (multi response)

Minimaal aantal vinkjes: 0

Vraagvoorwaarde actief	Vraag 29.0 (Are there any (expected) potential conflicts of land use at the ground level of the storage site?) Antwoord WEL gegeven: **Yes**. Indien niet voldaan spring naar: 0. Volgende vraag

☐ Agriculture/horticulture
☐ Nature conservation
☐ Industry
☐ Built-up area
☐ Wind mill parks
☐ Shipping lanes
☐ Nature parks
☐ Other:

31	What is the (industrial) history of the storage site?	Vinkvraag (multi response)

Minimaal aantal vinkjes: 1

☐ Natural gas production
☐ Oil production
☐ Natural gas storage
☐ Saline aquifer without other applications
☐ Other, namely:

32	If applicable, can you give a concise abandonment history of the storage site?	Open vraag (groot)

33	Is there any existing infrastructure that may affect the storage site?	Vinkvraag (multi response)

Minimaal aantal vinkjes: 0

☐ Oil / gas production infrastructure (e.g. wells, platform)
☐ Pipelines or cables
☐ Built up area (including future)
☐ Other:

☐ No Ex

34	Was there a need to acquire access to private properties for geophysical investigations?	Vraag (single response)

○ Yes
○ No [>> 36. What is the specific use of the reservoi...]

35	How much effort was needed for access?	Vraag (single response)

○ Little effort
○ Much effort

36	What is the specific use of the reservoir?	Vinkvraag (multi response)

Minimaal aantal vinkjes: 0

☐ Storage
☐ CO_2 enhanced oil/gas recovery

37	Are there any potential conflicts of use in the subsurface at the storage location?	Vraag (single response)

○ No
○ Yes

38	Which potential conflicts (to be expected)?	Vinkvraag (multi response)

Minimaal aantal vinkjes: 1

Vraagvoorwaarde actief	Vraag 37.0 (Are there any potential conflicts of use in the subsurface at the storage location?) Antwoord WEL gegeven: **Yes**. Indien niet voldaan spring naar: 0. Volgende vraag

☐ Oil/gas production
☐ Natural gas storage
☐ Groundwater extraction
☐ Geothermal energy project
☐ Heat / cold storage project
☐ Compressed air storage
☐ Radioactive waste disposal
☐ Other:

39	2. Permit application Which permits need to be in place before your project can go ahead?	Vinkvraag (multi response)

Minimaal aantal vinkjes: 0

- ☐ Act on Environmental Management (Wet Milieubeheer)
- ☐ Mining Law / Mining Decision (Mijnwet / Mijnbouwbesluit)
- ☐ Act on Spatial Planning (Wet Ruimtelijke Ordening)
- ☐ Act on Management of State Hydraulic Works (Wet Beheer Rijkswaterstaatswerken)
- ☐ Act on Nature Protection (Natuurbeschermingswet)
- ☐ Flora and Fauna dispensation (Flora- en Faunawet)
- ☐ National Coordination Regulation (Rijkscoördinatie regeling)
- ☐ Construction permit (Bouwvergunning)
- ☐ Circulaire Vervoer Gevaarlijke Stoffen
- ☐ Besluit Externe Veiligheid Inrichtingen

40	What is your experience with such permits?	Tabelvraag (single response)

Vraagvoorwaarde actief: Vraag 39.0
(2. Permit application

Which permits need to be in place before your project can go ahead?)
Minimaal **1** vinkjes.
Indien niet voldaan spring naar: 46. 3. Environmental Impact Assessment

	Good	Not good, not bad	Bad	
Act on Environmental Management (Wet Milieubeheer)	○	○	○	**Vraag voorwaarde** Afhankelijk van eerder gegeven antwoord 39.0 2. Permit ... (Act on Environmental Management (Wet Milieubeheer))
Mining Law / Mining Decision (Mijnwet / Mijnbouwbesluit)	○	○	○	**Vraag voorwaarde** Afhankelijk van eerder gegeven antwoord 39.0 2. Permit ... (Mining Law / Mining Decision (Mijnwet / Mijnbouwbesluit))
Act on Spatial Planning	○	○	○	**Vraag voorwaarde**

(Wet Ruimtelijke Ordening)				Afhankelijk van eerder gegeven antwoord 39.0 2. Permit ... (Act on Spatial Planning (Wet Ruimtelijke Ordening))
Act on Management of State Hydraulic Works (Wet Beheer Rijkswaterstaatswerken)				**Vraag voorwaarde** Afhankelijk van eerder gegeven antwoord 39.0 2. Permit ... (Act on Management of State Hydraulic Works (Wet Beheer Rijkswaterstaatswerken))
Act on Nature Protection (Natuurbeschermingswet)				**Vraag voorwaarde** Afhankelijk van eerder gegeven antwoord 39.0 2. Permit ... (Act on Nature Protection (Natuurbeschermingswet))
Flora and Fauna dispensation (Flora- en Faunawet)				**Vraag voorwaarde** Afhankelijk van eerder gegeven antwoord 39.0 2. Permit ... (Flora and Fauna dispensation (Flora- en Faunawet))
National Coordination Regulation (Rijkscoördinatie regeling)				**Vraag voorwaarde** Afhankelijk van eerder gegeven antwoord 39.0 2. Permit ... (National Coordination Regulation (Rijkscoördinatie regeling))
Construction permit (Bouwvergunning)				**Vraag voorwaarde** Afhankelijk van eerder gegeven antwoord 39.0 2. Permit ... (Construction permit (Bouwvergunning))
Circulaire Vervoer Gevaarlijke Stoffen				**Vraag voorwaarde** Afhankelijk van eerder

				gegeven antwoord 39.0 2. Permit ... (Circulaire Vervoer Gevaarlijke Stoffen)
Besluit Externe Veiligheid Inrichtingen	○	○	○	**Vraag voorwaarde** Afhankelijk van eerder gegeven antwoord 39.0 2. Permit ... (Besluit Externe Veiligheid Inrichtingen)

41	What is the stage of applications for permits?		Tabelvraag (single response)
	Approved	In proces	
Act on Environmental Management (Wet Milieubeheer)	○	○	**Vraag voorwaarde** Afhankelijk van eerder gegeven antwoord 39.0 2. Permit ... (Act on Environmental Management (Wet Milieubeheer))
Mining Law / Mining Decision (Mijnwet / Mijnbouwbesluit)	○	○	**Vraag voorwaarde** Afhankelijk van eerder gegeven antwoord 39.0 2. Permit ... (Mining Law / Mining Decision (Mijnwet / Mijnbouwbesluit))
Act on Spatial Planning (Wet Ruimtelijke Ordening)	○	○	**Vraag voorwaarde** Afhankelijk van eerder gegeven antwoord 39.0 2. Permit ... (Act on Spatial Planning (Wet Ruimtelijke Ordening))
Act on Management of State Hydraulic Works (Wet Beheer Rijkswaterstaatswerken)	○	○	**Vraag voorwaarde** Afhankelijk van eerder gegeven antwoord 39.0 2. Permit ... (Act on Management of State Hydraulic Works (Wet Beheer Rijkswaterstaatswerken))

Act on Nature Protection (Natuurbeschermingswet)	○	○	**Vraag voorwaarde** Afhankelijk van eerder gegeven antwoord 39.0 2. Permit ... (Act on Nature Protection (Natuurbeschermingswet))
Flora and Fauna dispensation (Flora- en Faunawet)	○	○	**Vraag voorwaarde** Afhankelijk van eerder gegeven antwoord 39.0 2. Permit ... (Flora and Fauna dispensation (Flora- en Faunawet))
National Coordination Regulation (Rijkscoördinatie regeling)	○	○	**Vraag voorwaarde** Afhankelijk van eerder gegeven antwoord 39.0 2. Permit ... (National Coordination Regulation (Rijkscoördinatie regeling))
Construction permit (Bouwvergunning)	○	○	**Vraag voorwaarde** Afhankelijk van eerder gegeven antwoord 39.0 2. Permit ... (Construction permit (Bouwvergunning))
Circulaire Vervoer Gevaarlijke Stoffen	○	○	**Vraag voorwaarde** Afhankelijk van eerder gegeven antwoord 39.0 2. Permit ... (Circulaire Vervoer Gevaarlijke Stoffen)
Besluit Externe Veiligheid Inrichtingen	○	○	**Vraag voorwaarde** Afhankelijk van eerder gegeven antwoord 39.0 2. Permit ... (Besluit Externe Veiligheid Inrichtingen)

42	What are the expected time trajectories for these applications or procedures?	Tabelvraag (single response)

	< One	One to two	Two to	> Three

	year	years	three years	years	
Act on Environmental Management (Wet Milieubeheer)	○	○	○	○	**Vraag voorwaarde** Afhankelijk van eerder gegeven antwoord 39.0 2. Permit ... (Act on Environmental Management (Wet Milieubeheer))
Mining Law / Mining Decision (Mijnwet / Mijnbouwbesluit)	○	○	○	○	**Vraag voorwaarde** Afhankelijk van eerder gegeven antwoord 39.0 2. Permit ... (Mining Law / Mining Decision (Mijnwet / Mijnbouwbesluit))
Act on Spatial Planning (Wet Ruimtelijke Ordening)	○	○	○	○	**Vraag voorwaarde** Afhankelijk van eerder gegeven antwoord 39.0 2. Permit ... (Act on Spatial Planning (Wet Ruimtelijke Ordening))
Act on Management of State Hydraulic Works (Wet Beheer Rijkswaterstaatswerken)	○	○	○	○	**Vraag voorwaarde** Afhankelijk van eerder gegeven antwoord 39.0 2. Permit ... (Act on Management of State Hydraulic Works (Wet Beheer Rijkswaterstaatswerken))
Act on Nature Protection (Natuurbeschermingswet)	○	○	○	○	**Vraag voorwaarde** Afhankelijk van eerder gegeven antwoord 39.0 2. Permit ... (Act on Nature Protection (Natuurbeschermingswet))
Flora and Fauna dispensation (Flora- en Faunawet)	○	○	○	○	**Vraag voorwaarde** Afhankelijk van eerder gegeven antwoord 39.0 2. Permit ... (Flora and Fauna dispensation (Flora- en Faunawet))

National Coordination Regulation (Rijkscoördinatie regeling)	○	○	○	○	**Vraag voorwaarde** Afhankelijk van eerder gegeven antwoord 39.0 2. Permit ... (National Coordination Regulation (Rijkscoördinatie regeling))
Construction permit (Bouwvergunning)	○	○	○	○	**Vraag voorwaarde** Afhankelijk van eerder gegeven antwoord 39.0 2. Permit ... (Construction permit (Bouwvergunning))
Circulaire Vervoer Gevaarlijke Stoffen	○	○	○	○	**Vraag voorwaarde** Afhankelijk van eerder gegeven antwoord 39.0 2. Permit ... (Circulaire Vervoer Gevaarlijke Stoffen)
Besluit Externe Veiligheid Inrichtingen	○	○	○	○	**Vraag voorwaarde** Afhankelijk van eerder gegeven antwoord 39.0 2. Permit ... (Besluit Externe Veiligheid Inrichtingen)

43	What would you consider a preferred best permitting strategy?	Vraag (single response)

○ Encompassing package covering CCS activities with strong involvement government
○ Separate permits & procedural coordination government

44	Do you consider permitting for the Act on Nature Protection as a large potential obstacle?	Vraag (single response)

○ No [>> 46. 3. Environmental Impact Assessment]
○ Yes

45	Do you have or foresee solutions to overcome or to cope with these obstacles?	Vraag (single response)

○ Amend current Act in order to mitigate obstacles

○ Other: [ ]

46	3. Environmental Impact Assessment Is an EIA (Environmental Impact Assessment / MER) already available?	Vraag (single response)

○ Yes
○ No [>> 48. At what date is a EIA needed?]

47	Please upload the EIA to the CATO-2 site and continue with the next question.	Tussenpagina

[>> 63. Do you have in particular data on:]

48	At what date is a EIA needed?	Vraag (single response)

○ 2010
○ Later

49	Who will perform this EIA (if known)?	Vraag (single response)

○ Performer: [ ]

○ To be decided

50	How do you define the 'zero alternative'?	Open vraag (groot)

51	How do you define 'other alternatives'?	Open vraag (groot)

52	How do you define ‘most environmentally friendly alternative’?	Open vraag (groot)

53	What environmental data are available for EIA?	Open vraag (groot)

54	Are there any data missing?	Multi-level vraag

○ Yes
  ○ Please fill out what data is missing:

○ No

55	Do you consider life cycle data (cradle-to-grave) as relevant?	Vraag (single response)

○ Yes
○ No

56	Are these life cycle data available today?	Vraag (single response)

○ Yes
○ No

57	What temporary impacts do you expect during construction?	Open vraag (groot)

58	How do you calculate cumulative impacts from other industries?	Open vraag (groot)

59	How do you assess following impacts?	Vinkvraag (multi response)

Minimaal aantal vinkjes: 0

☐ Emissions to air Vp

☐ Distraction of cooling water including harm to fish Vp

☐ Disposal of cooling water Vp

☐ Noise and/or vibrations during construction Vp

☐ Noise during operation Vp

☐ Light Vp

☐ Ship movements Vp

☐ Landscape Vp

☐ Above mentioned effects on nature conservation & flora/fauna Vp

☐ Safety (industrial and societal risks) Vp

60	Did you perform a cost-benefit analysis?	Vraag (single response)

○ Yes
○ No [>> 63. Do you have in particular data on:]

61	How was the cost-benefit analysis performed?	Open vraag (groot)

62	What were the main assumptions?	Open vraag (groot)

[>> 63. Do you have in particular data on:]

63	Do you have in particular data on:	Vinkvraag (multi response)

Minimaal aantal vinkjes: 1

Vraagvoorwaarde actief Vraag 2.0
(1. General aspects location

Which parts of the CCS chain are represented in your project?)
Antwoord WEL gegeven: **Capture**.
Indien niet voldaan spring naar: 0. Volgende vraag

☐ NOx, PM, SO2 emissions from the power plants with CCS
☐ NH3 and NMVOC emissions from solvents during operation
☐ Quantity and quality (toxicity) of solvent waste
☐ (Toxic) emissions to water
☐ Co-firing of biomass as a source of (potential) problems impacting CCS
☐ Other:

64	Will the CCS installation be operated continually or is flexible operation	Vraag

	allowed?	(single response)

- Continue
- Flexible

65	How does this impact the emissions?	Open vraag (groot)

66	How flexible is the capture installation for the use of different types of solvents?	Open vraag (groot)

Vraagvoorwaarde actief Vraag 2.0
(1. General aspects location

Which parts of the CCS chain are represented in your project?)
Antwoord WEL gegeven: **Capture**.
Indien niet voldaan spring naar: 0. Volgende vraag

67	Does flexibility with regard to solvents used impact the design and operation of the facility?	Vraag (single response)

Vraagvoorwaarde actief Vraag 2.0
(1. General aspects location

Which parts of the CCS chain are represented in your project?)
Antwoord WEL gegeven: **Capture**.
Indien niet voldaan spring naar: 0. Volgende vraag

- Yes
- No [>> 69. What environmental data is planned to be...]

68	What is the impact of the flexible solvents regarding the design and operation of the facility?	Open vraag (groot)

Vraagvoorwaarde actief Vraag 2.0
(1. General aspects location

Which parts of the CCS chain are represented in your project?)
Antwoord WEL gegeven: **Capture**.
Indien niet voldaan spring naar: 0. Volgende vraag

69	What environmental data is planned to be measured at the site?	Open vraag (groot)

70	What method (sampling / continuously) and measuring instrument are used?	Open vraag (groot)

71	Who will perform the measurement (internal / external)?	Vraag (single response)

- ◯ Internal
- ◯ External (please fill in the open field)

72	In what form (unit, time series, etc. Think of kg/year, kg/hour, mg/m3, kg/kWh, kg/PJi) is environmental data most useful for you? Please explain.	Open vraag (groot)

73	On what topics is environmental data most useful for you?	Vinkvraag (multi response)

Minimaal aantal vinkjes: 1

- ☐ CO_2
- ☐ BTEX (Benzene, Toluene, Ethyl benzene and Xylenes)
- ☐ NOx
- ☐ Particulate Matter (PM10)
- ☐ Fine dust (<=PM2.5)
- ☐ Nitrosamines
- ☐ Heavy metals
- ☐ Solvent waste
- ☐ Other (please specify):

74	Are there any other topics on which environmental data is most useful for you?	Open vraag (groot)

75	What would a 'Best Practice' for monitoring look like (see also heading 'Monitoring')?	Open vraag (groot)

76	4. Monitoring of emissions for the EU ETS Is there a monitoring system designed for the capture, transport and storage installation that is relevant for the EU ETS?	Vraag (single response)

- ◯ Yes
- ◯ No [>> 88. 5. Underground storage In whi...]

77	Is there a concept monitoring plan for the project for monitoring under EU ETS?	Vraag (single response)

- Yes
- No [>> 79. Describe the monitoring system for emiss...]

78	Has the measurement uncertainty of the monitoring system been evaluated?	Vraag (single response)

- Yes
- No

79	Describe the monitoring system for emissions under the EU ETS for all parts of the CCS chain applicable in your project (capture, transport, storage and all intermediates).	Open vraag (groot)

80	Which types of monitoring systems are evaluated for the monitoring of the storage site?	Open vraag (groot)

81	Which criteria have been evaluated to make a decision on the monitoring system for the storage site?	Open vraag (groot)

82	What is the chosen quantification method for emission reported for the EU ETS for all parts of the chain of CCS relevant for your project?	Open vraag (groot)

83	What is the composition of the CO_2 stream?	Tabelvraag plus

Vraagvoorwaarde actief
Vraag 77.0
(Is there a concept monitoring plan for the project for monitoring under EU ETS?)
Antwoord NIET gegeven: **No.**
Indien niet voldaan spring naar: 88. 5. Underground storage

In whi...

	Percentage (0-100%)
CO_2	
NOx	
PM10	
N_2O	

VOC	[ ]	
NH3	[ ]	
SO2	[ ]	
heavy metals	[ ]	

84	What are the ranges of the composition of the CO2 stream? What is critical to the composition: source, transport and/or storage?	Open vraag (groot)

85	Is the mass of CO_2 transported from source to the well determined by:	Vraag (single response)

- ○ mass balance
- ○ retention rates

86	Is verification of the monitoring system evaluated in the choice for a measurement system?	Open vraag (groot)

87	How is the quality of the measurement ensured (e.g. is the EN 14181 considered in the evaluation of the measurement system)?	Open vraag (groot)

Vraagvoorwaarde actief	Vraag 78.0 (Has the measurement uncertainty of the monitoring system been evaluated?) Antwoord WEL gegeven: **Yes**. Indien niet voldaan spring naar: 0. Volgende vraag

88	5. Underground storage In which phase of the lifecycle is your storage project?	Vraag (single response)

Vraagvoorwaarde actief	Vraag 2.0 (1. General aspects location Which parts of the CCS chain are represented in your project?) Antwoord WEL gegeven: **Storage**. Indien niet voldaan spring naar: 121. 6. Questions with a relevance for other ...

- ○ No activity yet [>> 121. 6. Questions with a relevance for other ...]
- ○ Pre-selection
- ○ Site qualification (prepare the license application) [>> 93. Is all existing data relevant to the CO_2...]
- ○ Operation [>> 93. Is all existing data relevant to the CO_2...]

○ Closure (cessation of injection) [>> 93. Is all existing data relevant to the CO_2...]
○ Post-closure (before transfer of responsibility to State authority) [>> 93. Is all existing data relevant to the CO_2...]
○ Post-closure (long-term stewardship/after transfer of responsibility to State authority) [>> 93. Is all existing data relevant to the CO_2...]

89	Did you or do you pre-select and prepare a list of potential storage options and ranked them according to their suitability for safe and effective storage?	Vraag (single response)

Vraagvoorwaarde actief Vraag 88.0
(5. Underground storage

In which phase of the lifecycle is your storage project?)
Antwoord WEL gegeven: **Pre-selection**.
Indien niet voldaan spring naar: 0. Volgende vraag

○ Yes
○ No [>> 93. Is all existing data relevant to the CO_2...]

90	Which potential storage sites have been pre-selected?	Open vraag (groot)

91	What are the main characteristics of the pre-selected sites (aquifer, gas field or oil field, type of seal, type of reservoir, presence of faults and wells)?	Open vraag (groot)

92	Which ranking criteria were or are used and what is the outcome of the ranking exercise?	Open vraag (groot)

93	Is all existing data relevant to the CO_2 containment and risk assessment readily available for your company?	Vraag (single response)

○ Yes
○ No [>> 95. Did you or do you need to acquire additi...]

94	What existing data is available from earlier hydrocarbon exploitation or other subsurface activities?	Open vraag (groot)

95	Did you or do you need to acquire additional data for the proper assessment of CO_2 containment and risks of CO_2 storage?	Vraag (single response)

○ Yes
○ No [>> 98. Did you or do you perform an assessment ...]

96	What additional data is acquired to formulate a hypothesis on cap rock/fault/reservoir/well behaviour? (please describe in very concise terms)	Open vraag (groot)

97	How is information managed so that it can be used to support the performance assessment?	Open vraag (groot)

98	Did you or do you perform an assessment of CO_2 containment and risk related to CO_2 storage?	Vraag (single response)

- Yes
- No [>> 105. Did you or do you develop a monitoring p...]

99	Is the concept of CO_2 containment clearly defined as well as the objective of the assessment and the setting of the site?	Open vraag (groot)

100	Have you identified non-integrity/leakage scenarios and if yes, which?	Open vraag (groot)

101	Is there a need for quantitative assessment of risks mentioned in the preceding question?	Open vraag (groot)

102	How do you estimate maximum pressure and capacity and how confident are you that predicted pressure range is not exceeded?	Open vraag (groot)

103	How do you demonstrate confidence in your understanding of the likely lateral extent of the storage system with time?	Open vraag (groot)

104	Did your performance assessment result in possible recommendations for additional site characterisation activities and if yes, which?	Open vraag (groot)

105	Did you or do you develop a monitoring plan to confirm CO_2 containment and to identify irregularities related to CO_2 storage?	Vraag (single response)

- Yes
- No [>> 109. Did you or do you develop a plan includi...]

106	Which tools did you select for monitoring containment and irregularities and why?	Open vraag (groot)

107	Is your monitoring plan compliant with the EU Storage Directive? If not, what additional monitoring would be required?	Open vraag (groot)

108	Did you adjust your original monitoring plan during operation? If yes, why?	Open vraag (groot)

Vraagvoorwaarde actief	Vraag 88.0 (5. Underground storage In which phase of the lifecycle is your storage project?) Antwoord WEL gegeven: **Operation**. Indien niet voldaan spring naar: 0. Volgende vraag
OF	
Vraagvoorwaarde actief	Vraag 88.0 (5. Underground storage In which phase of the lifecycle is your storage project?) Antwoord WEL gegeven: **Post-closure (before transfer of responsibility to State authority)**. Indien niet voldaan spring naar: 0. Volgende vraag
OF	
Vraagvoorwaarde actief	Vraag 88.0 (5. Underground storage In which phase of the lifecycle is your storage project?) Antwoord WEL gegeven: **Post-closure (long-term stewardship/after transfer of responsibility to State authority)**. Indien niet voldaan spring naar: 0. Volgende vraag
OF	
Vraagvoorwaarde actief	Vraag 88.0 (5. Underground storage In which phase of the lifecycle is your storage project?) Antwoord WEL gegeven: **Closure (cessation of injection)**. Indien niet voldaan spring naar: 0. Volgende vraag

109	Did you or do you develop a plan including preventive and corrective measures?	Vraag (single response)

- ○ Yes
- ○ No [>> 115. Is a plan for abandoning the wells in pl...]

110	Has the engineering design (no of wells, pressure) been adapted to minimize risks?	Vraag (single response)

- ○ Yes
- ○ No [>> 112. Are there existing wells which need a wo...]

111	How has the engineering design mentioned above been	Open vraag

	accomplished?	(groot)

112	Are there existing wells which need a workover as to minimize well leakage risks?	Vraag (single response)

- Yes
- No [>> 114. Which potential corrective measures have...]

113	Which workover activities have been proposed/were executed?	Open vraag (groot)

[>> 115. Is a plan for abandoning the wells in pl...]

114	Which potential corrective measures have been identified?	Open vraag (groot)

115	Is a plan for abandoning the wells in place as well as a plan for long-term monitoring and site maintenance?	Vraag (single response)

- Yes
- No

116	Have the results of the assessment been integrated with the monitoring plan and the plan with preventive and corrective measures?	Vraag (single response)

- Yes
- No [>> 121. 6. Questions with a relevance for other ...]

117	Did you or do you develop a risk register (table with identified risks, monitoring plan and preventive and corrective measures)?	Vraag (single response)

- Yes
- No

118	Do you use monitoring data to test your predictive reservoir model for the long-term performance of the storage site?	Vraag (single response)

- Yes
- No

119	Is a system for verification, reporting and updating in place?	Vraag (single

		response)

- ○ Yes
- ○ No

120	On the basis of which performance criteria do you conclude that the site is performing in a safe and effective way on the long term?	Open vraag (groot)

[>> 121. 6. Questions with a relevance for other ...]

121	6. Questions with a relevance for other CATO-2 work packages Is there data on measurement of CO_2 and measurement uncertainties available for evaluating and benchmarking in the CATO-2 project?	Vraag (single response)

- ○ Yes
- ○ No [>> 127. Are you interested to use a simple sprea...]

122	Are you interested in receiving support to measure environmental data?	Vraag (single response)

- ○ Yes
- ○ No

123	Are you willing to contribute with actual measurement of environmental data yourself?	Vraag (single response)

- ○ Yes
- ○ No

124	At what conditions are you willing to share environmental data within the CATO-2 community (formats, accessibility, etc)?	Open vraag (groot)

125	At what conditions are you willing to share environmental data outside CATO-2 community, for scientific and/or policy purposes (formats, accessibility, etc)?	Open vraag (groot)

126	What would you like to include in an Environmental Monitoring and Exchange plan to generate emission data?	Open vraag (groot)

127	Are you interested to use a simple spreadsheet tool that helps to make a Cost Benefit Analysis of environmental impacts (CBA) for CCS?	Vraag (single response)

- ○ Yes
- ○ No [>> 129. 7. Expectations from location managers/o...]

128	Are you interested as a user to play an active role in the development of such a tool?	Vraag (single response)

- ○ Yes
- ○ No

129	7. Expectations from location managers/operators/regulators Do the questions in this questionnaire cover the most important issues for safe and effective storage?	Vraag (single response)

- ○ Yes [>> 131. What type of guidance for licensing and ...]
- ○ No

130	Which issues are irrelevant and which issues are missing?	Open vraag (groot)

131	What type of guidance for licensing and certification do you need?	Open vraag (groot)

132	Please provide us with relevant references of publications which can be used in CATO-2. Examples are the storage permit, storage plan, monitoringprotocol, EIA, etc. The documents can be uploaded on the CATO-2 website www.CO_2-CATO.nl. Log in as a CATO-2 member, then go to Online workspace - SP4 Regulation and Safety - WP4.2 Permitting and best practice – Workspace.	Tussenpagina

Appendix B Additional questions posed during interviews with site managers

General aspects	
1	If your project starts as a pilot project, what are the main criteria to proceed or terminate the project?
2	If you decided to present the CCS project in the media or not, which were the reasons to do so?
3	If only a specific fraction of the CO_2 available is to be stored (not 100%), why is that?
4	If there are potential conflicts of land use (sea use), how will these conflicts be settled (possibly)?
5	If there is a relation or a possible conflict with a built up area, how will this be settled (possibly)?
6	If there is a possible conflict of the use of the subsurface, how will this be settled (possibly)?
Permitting	
7	If the experience with existing acts or regulations is not good, how could this be improved (connected to 10.4 - V45 and Question 10 below)?
8	In the framework of an Environmental Impact Assessment (EIA): is offshore storage of CO_2 an alternative (or onshore, if offshore is the default)?
9	Which are the most critical environmental impacts?
10a	Will condensation be allowed in the pipelines?
Monitoring	
10b	What are the fysical conditions (pressure, temperature) of the measured CO_2-stream?
10c	Have concrete/specific choices been made for measuring equipment?
Guidance for licensing	
10d	What type of guidance for licensing is needed and how could this materialise?
General remarks	

Appendix C General characteristics of the considered CCS projects

Name of the CCS project	PEGASUS (IJmond)	ROAD (Maasvlakte)	Chemelot (DSM, Geleen)	Magnum (Nuon)	RWE Eemshaven	Shell Barendrecht
Parts of the CCS chain represented	capture / transport / storage	capture / transport / storage	storage (in porous sandstone layeres)	capture / transport / storage	capture / transport / storage	capture / transport / storage
Project location	IJmond region	Rotterdam, Maasvlakte, E.ON Benelux site	Geleen	Eemshaven	Eemshaven	Barendrecht
Storage location	offshore	offshore (25 km of pipeline to TAQA field)	onshore	onshore	onshore (gas field)	onshore
Envisioned project start date (becoming operational)	2011 (demonstration unit, unit transported from US)	2015	2013 start pilot, 2014 go-no go for total project, start expected to be in 2016.	2015+ (depends on commissioning of Magnum and CO_2 capture plants)	2016	2012
Project termination date	phase 1; 2013, phase 2: min. 30 years	probably around 2035	2025/2030	unknown (installations will be designed for operation for decades, although demonstration stage itself may continue for more than 10 years)	2041	around 2045
Distance capture installation/ storage operation	storage location to be decided (offshore)		The storage operation is in the same area as the ammonia production. Distance is negligible. There is only transport from the plant to the injection well which is on the premises itself.		CCS project Eemshaven will presumably apply CO_2 storage in gas field in North Netherlands	20 km (16.5 km to Barendrecht, 3.5 km to Barendrecht-Ziedewij)
CO_2 capture technology	oxy-fuel	post-combustion	it concerns 100% CO_2	pre-combustion	post-combustion at 'CCS ready 2 * 860 MWe plant Eemshaven	it concerns 100% CO_2
CO_2 (to be) produced	depending on project success, up to 5-10 million tonnes per year	Around 1.1 Mtonnes per year will be captured. This corresponds to 250 MW_e equivalent.	1 Mtonne/yr		approximately 2.5 Mt/yr	around 11 Mtonnes
CO_2 (to be) captured	depending on project success, up to 5-10 million tonnes per year	The new coal fired unit MPP3 will produce 1070 MW of power.	Currently 500 ktonnes is used for soft drinks industry and urea production, the other 500 ktonnes is planned to be stored underground.	CO_2 capture rate is 1.3 - 4.5 Mt/yr (depending on gasifier and CO_2 capacity) / CO_2 stream may be 1.3 - 4.5 Mt/yr, depending on gasifier and the CO_2 capture capacity. 1.3 Mt/yr is minimum according to NER. 4.5 Mt/yr is technical limit (maximum). The captured CO_2 also depends on the quantity of biomass used.	1.1 Mt/yr to 250 MWe Eemshaven	11 Mtonnes
Ratio CO_2 production / capture	around 90%	250/1070		Depends on definition (as also natural gas is co-fired) / Part of the syngas will be fed to the capture unit, and 85% of the CO_2 content of this processed syngas will be captured (and stored). The percentage of 85% is a process optimum. However, which part of the syngas will be processed in the capure unit and which part will be by-passed, is not clear yet.	90 - 95% applies to 250 MWe Eemshaven	1
CO_2 source	gas-fired power plant	coal-fired power plant	ammonia production plant	Integrated (coal) Gasification Combined Cycle (IGCC)	coal-fired power plant	hydrogen factory of Shell in Pernis
Room for extension of CO_2 captured?	in principle, yes	Yes, more than 50%		Yes, more than 50% / 1.3 - 4.5 Mt CO_2/year presents range, of which 4.5 Mt/yr is maximum and corresponds to the CO_2 in the total syngas stream, and 1.3 Mt/yr is minimum according to NER (http://www.infomil.nl/onderwerpen/klimaat-lucht/ner/digitale-ner/)	no / provisional capacity CCS at 2 * 860 MWe PC plant Eemshaven, viz. 250 MWe, is not maximum	no
CO_2 (to be) transported ?	> 1,000,000 t CO_2/yr	> 1,000,000 t CO_2/yr		> 1,000,000 t CO_2/yr	> 1,000,000 t CO_2/yr	> 1,000,000 t CO_2/yr
Reservoir effective CO_2 capacity	sufficient, but depending on other CO_2 suppliers to same storage location.		> 10 million tonnes	reservoir not yet confirmed	no reservoir choice made yet	almost full
Website CCS project		www.road2020.nl	http://www.usgbv.nl/uploads/files/level0/Symposium/07%20Harrie%20Duisters%20CCS.pdf	http://www.nuon.com/nl/Images/Nieuwsbrief%201%20NUON%20MAGNUM%20NL_tcm164-68327.pdf	http://www.rwe.com/web/cms/en/55620/100-engineers/new-projects/power-station-construction-at-eemshaven-in-the-netherlands/	http://www..shell.nl/home/content/nld/environment_society/co2_storage/

Name of the CCS project	TAQA P18	Wintershall Q08	DAP (Delft Aardwarmte Project)	CRUST (K12-B, GdF Suez)	CO_2 Catch-up Buggenum (Nuon)	CO_2 capture project Twence B.V.
Parts of the CCS chain represented	transport / storage	storage	storage (in saline aquifer)	capture / storage	capture	capture
Project location	Block P18, 20 km offshore from Maasvlakte	Offshore, 6 km off Egmond	Delft	K12-B (Dutch North Sea)	Buggenum	Hengelo
Storage location	offshore	offshore	onshore (depth 2000 - 2500 m)	K12-B offshore Dutch North Sea	Not applicable	Not applicable in this stage
Envisioned project start date (becoming operational)	The project is in the stage of permitting, with injection anticipated in 2015	earliest 2015 (when the project will start depends on decisions to be made by the Rotterdam Climate Initiative (RCI))	Stage 1, realisation of geothermal project. Stage 2, development and realisation of CO_2 capture and storage, which is a research driven project. It will take another 2 years before permits will have to be acquired and 4 yours for realisation of CO_2 capture and storage.	2004	Testing pre-combustion CO_2 capture technology at existing IGCC plant, start Q3 2010	CO_2 capture at waste processing plant Twence B.V., R&D stage
Project termination date	after 2025	earliest 2015 (estimated max of 12 years after start-up)	Capacity of CO_2 storage maximum 2.5 Mt CO_2. The project starts with capacity of 5,000 t/yr, final date unknown. CO_2 is captured at Combined Heat and Power (CHP) plant on the TU Delft site. Barendrecht project causes negative climate for DAP project. In the past comparable project of Gaz de France offshore did not pose problems.	2006	2012	N/A
Distance capture installation/ storage operation	P18: 20 km, P15: 40 km		At the site of the CHP plant	nil	Not applicable	Not applicable at this stage
CO_2 capture technology			post-combustion, however, probably not based on MEA, but CO_2 solution in cold (retour) water	Pre-combustion	Pre-combustion (water-gas shift reaction and capture with solvent)	Post-combustion
CO_2 (to be) produced			not precisely known, possibly 20,000 t/yr.	0.4 Mt/yr	(1.25 Mt/yr)	N/A
CO_2 (to be) captured	In demonstration project 5.5 Mt CO_2 to be captured and stored, 1.1 Mt CO_2 per year. Storage capacity TAQA's offshore gas reservoirs P15 & P18 approx. 80 Mt CO_2 but practically about 60 Mt CO_2 with 30 Mt in P18		5,000 t/yr	20,000 t/yr	10,000 t/yr	N/A
Ratio CO_2 production / capture				20	125	N/A
CO_2 source	any emitter, most likely from the Maasvlakte. New E.On power plant (approx. 1,000 MW_e) Maasvlakte is the most concrete	unkown (It will come from the Rotterdam area as part of the RCI. If the OCAP pipeline will be used for this project the CO_2 stream will have to be pure because parts are transported to the greenhouses).	CHP plant	CO_2 rich natural gas	IGCC Buggenum	Waste processing plant
Room for extension of CO_2 captured?			yes, in principle the capacity of the aquifer is large enough to enable increased capacity	yes	Not applicable (pilot project)	Not applicable in this stage
CO_2 (to be) transported ?	> 1,000,000 t CO_2/yr	> 1,000,000 t CO_2/yr		No	No	Not applicable
Reservoir effective CO_2 capacity	60 Mtonnes	7.8Mt		8 Mt of CO_2	Not applicable	Not applicable
Website CCS project	http://www.taqa.ae/assetsmanager/files/pdf/co2.pdf	http://www.vrom.nl/pagina.html?id=37910	http://www.tudelft.nl/live/pagina.jsp?id=c4df275e-60f2-4272-8ea8-a26533a6c792	http://www.igu.org/html/wgc2006/pdf/paper/add11170.pdf.	http://www.gpisd.net/vertical/Sites/%7B1510F0B9-E3E3-419B-AE3B-582B8097D492%7D/uploads/%7B84FC361B-D7EE-42A3-AB99-5928C3F79E33%7D.PDF	http://www.thermalnet.co.uk/Resources/user/docs/04%20Combustion%20update%20Vienna.pdf

Appendix D Acts and regulations

1	Aanlegvergunning Wet Ruimtelijke Ordening (WRO), artikel 14
2	Algemene Maatregel van Bestuur (AmvB) boren
3	Besluit Externe Veiligheid Inrichtingen
4	Besluit Risico's Zware Ongevallen (BRZO)
5	Besluit Stortplaatsen en Stortverboden (Bssa)
6	Bouwvergunning Woningwet
7	Circulaire Transport Gevaarlijke Vloeistoffen
8	Emissievergunning Wet Milieubeheer and Richtlijn voor Emissiehandel (ETS, Emission Trading Scheme)
9	Kaderrichtlijn voor Afvalstoffen
10	Keurvergunning Waterschap
11	Landelijk Afvalbeheerplan
12	Meetplan bodembeweging Mijnbouwwet and Mijnbouwbesluit
13	MER procedure Besluit Milieu-effectrapportage en Richtlijnen voor Milieu-effectrapportage
14	Ontheffing Lozingenbesluit
15	Opslagplan Mijnbouwwet (artikel 39) en Mijnbouwbesluit (artikel 26)
16	Opslagvergunning Mijnbouwwet (artikel 25) and Mijnbouwbesluit
17	Opsporing-/exploratievergunning Ministerie EZ
18	OSPAR verdrag
19	Protocol verdrag van Londen (Verdrag inzake de voorkoming van verontreinigingen van de zee ten gevolge van het storten van afvalstoffen en andere stoffen)
20	Revisievergunning puttenterrein Wet Milieubeheer (artikel 8.4 lid 1)
21	Sluitingsplan Mijnbouwwet (artikel 39) and Mijnbouwbesluit

22	Toestemming tot aanleg buisleiding in buisleidingstraten
23	Vergunning Bovengronds Wet Milieubeheer
24	Vergunning document Voorontwerprapport Arbobesluit (artikel 2.4.2) and Arbo-regeling (artikel 3.6 etc)
25	Vergunning Flora en faunawet
26	Vergunning Lozingsbesluit Bodembescherming
27	Vergunning Monumentenwet
28	Vergunning Natuurbeschermingswet
29	Vergunning Onttrekking Grondwater Grondwaterwet
30	Vergunning Rijkscoordinatieregeling
31	Vergunning Spoorwegwet
32	Vergunning Wet Beheer Rijkswaterstaatwerken
33	Vergunning Wet Milieubeheer (artikel 8.1 and 8.2 lid 3), IPPC-richtlijn (Europese richtlijn voor integrale preventie van luchtverontreining) and Richtlijn voor Milieuaansprakelijkheid
34	Vergunning WRO
35	Vergunning Wet Verontreiniging Oppervlaktewateren
36	Vergunning Wet Verontreiniging Zeewater
37	Vergunning Wet op de Waterhuishouding
38	Voorbereidingbesluit en wijziging Bestemmingsplan WRO (artikel 3.3)
39	Winningplan Mijnbouwwet and Mijnbouwbesluit
40	Winningsvergunning Ministerie EZ en richtlijn voor Veiligheid en Gezondheid in de Winningsindustrie