Briefing on identified best practices in relevant networks

Prepared by: M. Mozaffarian (ECN, Work package leader)
H. Groenenberg* (ECN)
T. van Harmelen (TNO)
A. van Horssen (TNO)
M.D.C. van der Kuip (TNO)
P. Lako (ECN)
B. Stortelder (KEMA)
J. van Wingerden (KEMA)

* *working at Ecofys since August 2010*

Reviewed by M. Nepveu (TNO)
P.F. van den Oosterkamp (ECN)
R. Wit (SNM)
J. Coolen (SdN)
M. Mozaffarian (ECN)

Approved by: J. Brouwer (CATO-2 Director)

1 Executive Summary

This document is the first briefing of the five-year (2009-2013) research project (Mozaffarian *et al.*, 2010), that has been carried out within the framework of the CATO-2 program. The document has been reviewed both by two project partners (TNO, ECN), as well as by the North Sea Foundation[1] (Stichting de Noordzee) and the Netherlands Society for Nature and Environment (Stichting Natuur & Milieu).

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.

[1] See Appendix B.

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)

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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	CO2 Enhanced Coal Bed Methane
EIA	Environmental Impact Assessment
EU ETS	European Union Emission Trading System
GIIP	Gas Initially In Place
IGCC	Integrated (coal) Gasification Combined Cycle
IRR	Internal Rate of Return
LCA	Life Cycle Analysis
NER	Nederlandse Emissie Richtlijn
NOx	Nitrogen Oxides
NSF	North Sea Foundation
PM	Particulate Material
POT	Payout Time
SdN	Stichting de Noordzee
SNM	Stichting Natuur & Milieu
WP	Work Package

3 Briefing on identified best practices in relevant networks

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.

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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 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, of which 9 did fill in the questionnaire. It should be mentioned, that all of these projects are still in the development phase and none are operational. In order to further an understanding of the responses, additional bilateral interviews, including additional questions, were conducted with the location managers.

The results of both the questionnaire and the subsequent interviews are summarised in the following paragraphs. This document is the first report of the five-year (2009-2013) research project within the CATO-2 program.

General aspects location

Some general characteristics regarding the CCS projects in the Netherlands, e.g. size, transport distance, type of project, are presented in Appendix A.

Capture

The capture technologies considered are: *post-combustion* with CO_2 source either being coal-fired plants or a combined heat and power plant, *pre-combustion* with CO_2 source being an integrated (coal) gasification combined cycle plant, and *oxy-fuel* with CO_2 source being a gas-fired power plant. In addition, in two of the concerned CCS projects the CO_2 is a 100% pure stream from either an ammonia production plant or from a hydrogen plant.

Transport

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 an existing gas pipeline are reported as options. A new pipeline could be built over dimensioned, so that possibly more projects could be connected and make use of it. In case of about half of the projects the operational transport conditions (pressure, distance, temperature, and purity) to be met by designing are already defined. Concerning the remaining projects, either the way of transport should still be decided on, or the operational transport conditions have to be defined by the pipeline operator, or no information is available. The design and material specifications (dimensions, material, lining) of the pipeline 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 an engineering study.

Storage

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 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. The aquifer considered in the DAP project has no other application; this aquifer is on top of a reservoir which is used for geothermal energy production.

The majority of respondents do not expect any potential conflicts of land use at the ground level of the storage site. Concerning the DAP project (see Appendix A for details), 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 within this DAP project would be enlarged, which may increase the CO_2 capture potential.

In case of five of the nine projects considered, 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 the TAQA site (see Appendix A for details) 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.

One of the nine projects 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.

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.

In four of the nine considered CCS projects one or more potential conflicts of use in the subsurface at the storage location might occur. Concerning the Chemelot project when CO_2 is stored, the present coal layer cannot be produced anymore from this site (which is anyhow not likely in view of the depth of the coal bed). A possible spin-off could be ECBM (CO_2 Enhanced Coal Bed Methane) from the coal bed above the CO_2 storage site. In case of the 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. With respect to the TAQA project, new CCS activities could change the economic perspective of the gas reservoirs, that are never completely empty, but at a certain moment not profitable anymore. 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. In case of the 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.

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. In case of the DAP project next to CO_2, also NO_x from the CHP plant will simultaneously be injected.

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.

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. At least ten Dutch acts and regulations are deemed to be relevant for CCS projects. A short explanation of these acts and regulations is given below.

Act on Environmental Management (Wet Milieubeheer)

This act 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 this act.

Mining Law (Mijnbouwwet)

This law is applicable to CO_2 storage, both onshore and offshore. Therefore, it is part and parcel of the permitting procedures of the CCS projects involved.

Act on Spatial Planning (Wet Ruimtelijke Ordening)

This act 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.

Act on Management of State Hydraulic Works (Wet Beheer Rijkswaterstaatswerken)

This act 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.

Act on Nature Protection (Natuurbeschermingswet)

This act applies if the (CO_2 capture) project is to be realised in the neighbourhood of a nature reserve. Some projects involve CO_2 transport and storage in industrial or urban areas, to which this act 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.

Flora and Fauna Law (Flora- en Faunawet)

This law 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.

National Coordination Regulation (Rijkscoördinatie regeling)

This regulation 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 the National Coordination Regulation if the CCS project is of national significance, but it is not required.

Construction permit (Bouwvergunning)

A Construction permit is needed for a CO_2 capture plant and for a CO_2 transport pipeline. The law may apply to a CO_2 storage facility if it is onshore.

Circular on Transport of Hazardous Substances (Circulaire Risiconormering Vervoer Gevaarlijke Stoffen)

This is mentioned only in a few of the involved CCS projects, which may be explained by the fact that some projects have not yet applied for permits.

Decision on External Safety of Installations (Besluit Externe Veiligheid Inrichtingen)

This 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).

Based on the stakeholders’ responses, the total length of the permitting procedure seems to be two to three years. The required (or expected) length for each separate permission has been reported to be from less than one year up to two years. The stakeholders were also asked to qualify their experience with specific laws or regulations as ‘good’, ‘not good and not bad’ or (possibly) ‘bad’. In most cases they have qualified their experience as ‘not good and not bad’, followed by good qualifications (in case of the Mining Law, construction permit, Decision on External Safety of Installations, Circular on Transport of Hazardous Substances, and the Act on Spatial Planning). One respondent had bad experiences with the Act on Environmental Management, another respondent with the Act on Nature Protection.

Environmental Impact Assessment

The questions posed within the questionnaire, involve the following different themes:

- Environmental Impact Assessment (EIA);
- Environmental data availability;
- Life Cycle Analysis (LCA);
- Cost-Benefit Analysis (CBA);
- Measurements of environmental data;
- Respondents’ opinion on environmental issues.

Not all respondents did answer the questions at the same level of detail, but often the answers included valuable additional information.

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. 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.

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 power generation. But also, the production of the CCS facilities are covered in a full Life Cycle Analysis. Half of the respondents consider LCA data as relevant. Most of the respondents think these data are not available yet (to them).

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 costs. No details on the assumptions and methodology for the CBA 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). In fact, it concerns not so much a CBA, but a profitability analysis.

Not all respondents already know which measurements (of environmental data) will be performed in the project. How and by whom the measurements will be performed has in general not been decided yet.

Most respondents indicate that environment is considered to be a relevant issue. Especially the capture plants are interested in the environmental data on NOx, 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.

Underground storage

The goal of the underground storage questions was to obtain knowledge on the risk assessment procedures currently used/performed, the monitoring procedures stated in the monitoring plan, and the preventive and corrective measures defined. The results would provide insight into the phase of the project, the procedures currently used and the requirements and needs of the location managers.

The questions concerning underground storage involve the following topics:

- Phase of the project;
- Selection of the storage site;
- Data availability and data acquisition;
- Performance/risk assessment;
- Monitoring;
- Preventive and corrective measures;
- Abandonment;
- Risk management.

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 9 storage sites investigated in this project is yet in the injection phase, closure or the post-closure phase. Most of the projects are in the pre-selection or in the site qualification phase, prior to the permit application. The fact that several procedures and processes will be executed in a later phase of a project resulted in decreasing number of answered questions 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.

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 of 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.

One-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, 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.

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 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.

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.

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.

Probably due to the early stage of the storage projects considered, a preventive and corrective measures plan was not developed yet in most of the 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.

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.

Especially the questions related to risk management were answered by only some of the respondents. 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 in the long term is described in one case in their EIA.

In order to get more insight into the current gaps that are present in underground storage risk management procedures and processes, a set of additional questions have been formulated. These questions concern the risk management procedures, and the assessment of CO_2 containment, preventive and corrective measures, monitoring tools, and the priorities of the location managers.

Monitoring of emissions for the EU ETS

Monitoring of the CO_2 emissions for the EU ETS takes place both during the operation phase, and after the storage site has become abandoned. During the operation phase monitoring is required for the quantification of the amount of CO_2 captured and transferred into the transport system, and the 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 responses were rather poor.

In most of the cases a monitoring system for the CCS activity, as part of the EIA, is already designed or is in preparation. For the selection of monitoring systems accuracy is the most important criterion. 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.

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.

Generally, the amount of CO_2 produced, is based on the measurement of the fuel consumption. As far as the project managers 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.

In most of the cases the CO_2 stream consist for 99%-100% of CO_2. In some cases the CO_2 purity is not clear yet; it depends on the outcome of process optimisation experiments. It may 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.

The physical conditions of the CO_2 stream for each project are very different. For those projects that are in an early stage of development the physical conditions are not always clear, and have to be researched first. These conditions depend for instance on the amount of CO_2 captured, distance to the storage and the conditions in the storage.

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 no response from the project managers was received. It seems that at the current stage of the projects not much attention has been given to these items yet. 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.

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.

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4 References

Mozaffarian, M., H. Groenenberg, T. van Harmelen, A. van Horssen, M.D.C. van der Kuip, P. Lako, B. Stortelder, J. van Wingerden (2010): *Best practices in CCS demonstrations; Progress report.* CATO-2-WP4.2.A-D01-REP, October 2010

Appendix A 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 B Comments of the North Sea Foundation (NSF), composed by Joop Coolen

Introduction

The North Sea Foundation (NSF)[2] is the nature and environmental organisation dedicated to the sustainable use of the North Sea. A clean and healthy sea full of fish, birds, dolphins and other life - this is our dream. Shipping, fisheries, spatial planning and nature conservation are our key areas of focus.

The North Sea Foundation is opposed to the capture and storage of CO_2 in general. CCS potentially will slow down the transition to sustainable energy solutions as it will facilitate the prolonged use of unsustainable fossil fuels and is subsidised with money that could be spent on development of sustainable alternatives. CCS is not a sustainable energy technology.

However, CCS could, in certain areas, be used to decrease the environmental impact of activities. Also, we foresee that CCS will happen on the short term anyway, hopefully as a temporal solution which does not decrease the transition to sustainable energy sources. Given this, NSF has agreed to review this report, hoping our insights will help decrease the environmental impact of CCS.

NSF has not checked all of the statements in the report to be fact or not. This report does not reflect the opinion of NSF. We do have, however, some suggestions and reactions to the report. Our findings are stated in the following paragraph.

Reaction to report

NSF has some suggestions or reactions on parts of the report, summed up here for each relevant topic.

Transport

Transport should be realised as much as possible with pipelines already present. E.G. using pipelines which were used for transportation of other gases. Building new pipelines can have large environmental impacts, both on land as offshore. Reused and new pipelines should be 100% leakage proof. This is especially important offshore as escaping CO_2 has an acidifying effect on water, killing of all nearby life.

Investment in CCS project

As with pipelines, it is preferable to reuse offshore platforms previously exploited for gas & oil. However, it is only acceptable to leave abandoned platforms when it is 100% certain that the platform is needed for CCS. Possible or uncertain application of platforms may never be used as

[2] Stichting de Noordzee (SdN)

an excuse not to decommission platforms. Decommissioning is mandatory as soon as the platform is abandoned.

Permitting of CCS – Nature protection act

The nature protection act is applicable to all activities, not only to activities in the neighbourhood of nature reserves. Especially on the North Sea, several protected species migrate across all of the North Sea, thus the nature protection law is applicable to all the potential storage locations on the North Sea.

Permitting of CCS – Flora and Fauna law

As with the nature protection act, the flora and fauna law is applicable to all activities, anywhere. E.G. Harbour Porpoise, a protected species, can be encountered anywhere in the North Sea so effects on species like this should always be assessed, regardless the location on the North Sea.

EIA – LCA

It is disappointing to read that only half of the respondents to the survey consider LCA data as relevant. LCA is very relevant for a technology as CCS. If CCS is added to, e.g. power plants, the negative effects of the plant increase on every aspect except CO_2 emission. NFS would very much like to know in how far the addition of CCS to power plants will in- or decrease the total environmental and societal impact of coal or gas fired power plants. Only a complete LCA of CCS will result in a complete picture of the effects of CCS.

EIA – CBA

As with LCA, it is disappointing to read that in all CBA performed for CCS, external costs are ignored. External costs will increase with the application of CCS to power plants, thus are very important to include in the CBA.

Underground storage – site selection

In this chapter several criteria used for site selection are summed up. Again, it is disappointing to read that, although earlier in the report respondents stated that EIA is important, the environmental impact is not a criterion used in site selection. Potential effects on ecology and other environmental impacts should be one of the main criteria for selecting sites for storage. Especially offshore, impacts on marine life can be devastating if CO_2 escapes from storage. This effect will be much larger than for storage on land.

Underground storage – monitoring

Monitoring plans should absolutely include a scheme to assess if CO_2 is escaping the storage location. As mentioned above, escaping CO_2 can have deadly, large scale effects on marine life. There must be 100% certainty that stored CO_2 will not leak before progression to large scale application can be made.

Underground storage – monitoring abandoned sites

After abandonment, monitoring of sites for leakage and other effects should be continued.