Recent developments in the Dutch CATO programme[1]

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Introduction

The CATO programme represents a strong knowledge network in the field of CO_2 Capture and Storage (CCS) in the Netherlands. The aim of CATO is to identify whether and how CCS can contribute to a sustainable energy system and under which conditions this option could be implemented in the energy system. CATO is executed by a consortium of Dutch companies, research institutions, universities and environmental organisations, managed by the Utrecht Centre for Energy research (UCE). Given its size, 25 million Euro, the CATO programme can be regarded as the national research programme on CCS in the Netherlands, and runs from 2004 until 2009. The Dutch government supports CATO with 50% subsidy from the BSIK programme of the Ministry of Economic Affairs.

This paper presents an overview of the recent developments in the programme. Details of the following research subjects are discussed in separate papers at GHGT-8.

System Integration

Based on an interactive dialogue process with a wide range of stakeholders a sustainability framework for CCS options is being developed by Utrecht University and Ecofys and will be deployed in comparing CCS options. A PhD study at Utrecht University is devoted to the assessment of six different capture technologies, and started with (1) Post-combustion capture by chemical absorption technologies, (2) Chemical Looping Combustion (CLC) / Sorbent Energy Transfer System (SETS), and (3) Advanced Zero Emission Power Plant (AZEP). Three pre-combustion technologies will follow. In each case, the most important improvement options for the technologies are identified and a rough quantification of process parameter improvements will be done. As part of an evaluation and classification of Dutch storage options a master thesis is carried out, with the main goal to get better insight in the storage potential of onshore aquifers in the Netherlands and set up a MCA methodology for the classification of Dutch storage potential on the

[1] CATO is the Dutch national research programme on CO2 Capture and Storage. CATO is financially supported by the Dutch Ministry of Economic Affairs (EZ) and the consortium partners. (www.co2-cato.nl)
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basis of risk profiles. Four PhD theses at Utrecht University are devoted to scenario analysis and strategies for large-scale introduction of CCS-bases systems in the Netherlands: Impact Analysis (including Environmental Assessment), System Analysis, Techno-economic Performance, and Analysis of Energy Infrastructure. In a separate PhD activity the CCS innovation system is analysed (mapping functional patterns, understanding knowledge development and diffusion, etc.)

Capture

Targets in capture research are to achieve an efficiency loss in power plants of less than 5% (abs) and to reduce the costs of capture to below 20 €/ton.

Membrane contactors for post-combustion capture were tested and selected by TNO Science and Industry. This involves the use of membranes for both the absorption and desorption process. Up-scaling and validation is now taking place. A lot of the solvent research work is carried out at Twente University, with three PhD students. A test facility will be built using flue gases from a coal-fired power plant, to demonstrate and test innovative post-combustion capture technologies, at a scale of 100-200 kg CO2/hour. A basic design has been made and the next steps are the selection of the test site and the selection of the supplier. The plant design will be based on the use of novel amino-acid salt solutions as solvents for post-combustion capture. Close collaboration with the EU Integrated Project CASTOR is established.

For pre-combustion capture, system models have been developed by ECN. This has been done for both the application of palladium alloy membrane reactors as well as SERP (Sorption Enhanced Reaction Process). Different membrane reactor designs have been evaluated. A successful proof-of-principle test with a membrane reactor has been carried out. A significant shift in methane conversion beyond chemical equilibrium has been observed. System assessment studies showed efficiencies above 50%. A proof-of-principle has been delivered for SERP operation at atmospheric pressure over more than 100 cycles with an average methane conversion of 97% and no loss in performance. An industrial applicable production method for hydrogen selective membranes is being developed.

TNO Science & Industry also carries out research on chemical looping combustion, in collaboration with Twente University. A membrane reactor concept operating at high pressure and hence allowing operation in connection with gas turbines is now under construction.

KEMA, representing six Dutch electricity companies within CATO, has performed a baseline study on electricity production processes. For two reference plants the technical, economical and environmental possibilities and consequences of CO2 capture were described and discussed.

Storage

Gas fields: Reservoir simulation modelling was performed for the CO_2 injection experiments in the K12-B gas field in the North Sea, operated by Gaz-de-France Netherlands. The history-matched model was able to predict the monitored pressure increase in the reservoir as a consequence of CO_2 injection. The second CO_2 injection experiment focuses on the feasibility of additional gas recovery resulting from CO_2 injection. TNO-NITG calculated the storage capacity of the whole K12-B field to be around 20 Mt CO2, higher than estimated earlier. This part of the CATO-project is aligned with the European projects CASTOR (reservoir simulation) and CO2GEONET (tracer study). More details on K12-B research are provided in the GHGT-8 paper by Kreft et al.

Coal fields: For ECBM research an extensive database on coal storage capacities for different gases was made at Delft University of Technology (DUT). The gas diffusion process speed and the effect of water presence were determined in the laboratory, as well as the adsorption/desorption mechanisms. Experiments were carried out to determine O2 behavior when impure CO2 is injected, and models were developed at scales from maceral level to seam level. Simulation tools for ECBM were validated, and the geo-mechanical behavior of the subsurface during CO_2 injection was determined. Utrecht University, together with TNO-NITG, performed experiments to determine adsorption mechanisms at the microscopic/maceral level, experiments to determine CO2 and flue gas effects on swelling/shrinkage. Also the electrical properties of coal were measured, for

monitoring purposes. The ECBM activities are guided and supported by Shell International Exploration and Production. Shell also made an inventory of modeling algorithms.

Mineralization

Subsurface mineralization is undertaken jointly by Shell and Utrecht University. Shell compiled existing simulation codes and tested them to address subsurface mineralization. Reaction, flow and permeability evolution lab experiments were performed by Utrecht z University on geologic materials (in-situ conditions, high pressure and high temperature) and laboratory experiments on rock mechanical response to reaction and effects of stress on reaction rate were carried out. Feldspars turned out to have extremely slow reaction kinetics even with enhancements for lab scale experiments. The potential of subsurface mineralization of CO_2 in the Netherlands will be estimated.

Surface mineralization: TNO S&I studied new routes based on acidic dissolution of silicate minerals. Due to the rapid dissolution reaction of magnesium silicates in strong acids, particle sizes need not be ultra fine, thus substantial savings on milling energy are possible.
Experimental research performed by Geochem was focused upon two ways of extracting magnesia from olivine. First experiments were carried out to extract magnesia under relatively mild extraction conditions. For these experiments sodium sulfate and weak acids like acetic acid and a solution of potassium pyrosulfate were used. The objective of these experiments was to find a process in which magnesia does not need to be separated from the leaching solution. The second extraction path investigated is the extraction of magnesia using nitric acid.
ECN made an inventory of existing literature and experimental results obtained earlier. This has resulted a.o. in the publication of a paper on steel slag carbonation [Huijgen et al, 2005, Environment, Science and Technology, 39(24), 9676-9682]. In this paper, the reaction mechanisms of aqueous steel slag carbonation process are investigated and process conditions required for substantial conversion of this industrial residue are identified. It was shown that steel slag carbonates rapidly relative to primary ores and therefore relatively mild process conditions are sufficient.

Monitoring, safety and regulations

In alignment with the EU Network of Excellence CO2GEONET, TNO-NITG formulated a draft version for the risk assessment framework and terminology. Further adjustments to the existing risk assessment methodology have been defined, which are now being implemented.
A draft report on monitoring requirements has been finished and is now being reviewed. Monitoring requirements have been identified and are related to the major phases of the storage lifecycle: preparation, operation, abandonment and post-abandonment.
In the area of acoustic monitoring technology a post-doc at Delft University of Technology is working on an ultrasone wave experiment. TNO-NITG and DUT consider the use of seismic data from the RECOPOL-project and alternatives for this dataset. The applicability of cross-well seismic techniques in the detection of CO_2 has been investigated and is being reported (TNO). A new theory for interpretation of these data is tested.

Public perception and communication

CCS options are largely unknown to the general public, therefore it is necessary to provide respondents with well-balanced information on the most important consequences of each CCS technology, before asking their opinion. This was done in a so-called ICQ (Information-Choice Questionnaire). The information in the ICQ was compiled by various energy experts and translated for laymen. After respondents processed this information, they were asked for their opinions and attitudes towards six CCS options. The ICQ was administered to a representative sample of the Dutch population (N=1005) in December 2004.

Table 1 Contributions of CATO to GHGT-8

First author	Title paper
M.R.M. Abuzahra1 TNO Science and Industry	The Technical and Economical Analysis of CO2 Capture Based on an Absorption/Desorption Process Using Mono-Ethanolamine
Klaas van Alphen Utrecht University	Social Acceptance of Carbon Dioxide Sequestration in the Netherlands
Klaas van Alphen Utrecht University	Towards Successful CCS Trajectories: An Innovation System Perspective
Marjolein de Best-Waldhober Leiden University	Informed Public Opinions on CO2-Capture and Storage Technologies
Paul van Beurden ECN	Catalysts for Hydrogen Production in Membrane Reformers
Ruud W. van den Brink ECN	Sorption-enhanced hydrogen production for pre-combustion CO2 capture
Machteld van den Broek Utrecht University	Timing is a crucial factor in a CCS development pathway, the case of the Netherlands
Paul D. Cobden ECN	Comparison of Several Pre-Combustion Decarbonisation Routes for Hydrogen Production from Methane
Dancker Daamen Leiden Universiy	Pseudo-opinions on CCS technologies
Kay Damen Utrecht University	Developing strategies for large-scale implementation of CO2 capture and storage: a case study for the Netherlands
P.W.J. Derks Twente University	Solubility of Carbon Dioxide in Aqueous Blends of Piperazine and N-Methyldiethanolamine
Jan Wilco Dijkstra ECN	Development of a hydrogen membrane reactor for power production with precombustion decarbonisation
Wouter Huijgen ECN	Aqueous mineral carbonation as a possible CO2 sequestration process: energetic efficiency and costs.
Joris Koornneef Utrecht University	Environmental Impact Assessment of Carbon Capture & Storage in the Netherlands
Erik Lysen Utrecht University	Recent developments in the Dutch CATO programme
Magdalena Majchrowicz Twente University	Precipitation in amino acid salt based CO2 absorption systems
Bert van der Meer TNO Built Environment and Geosciences	Enhanced Gas Recovery Testing in the K12-B Reservoir by CO2 Injection, a Reservoir Engineering study
L.G.H. van der Meer TNO Built Environment and Geosciences	An Enhanced Method to Predict the CO2 Solubility Effects in Water at the Reservoir Scale over a very Long Time Scale
Emma ter Mors Leiden University	The influence of communicator expertise and trustworthiness on acceptance of CCS technologies
Ad Peeters Utrecht University	Technological and Economic Comparison of CO2 Capture Technologies including Development Potential Evaluations
Andrea Ramirez Utrecht University	Defining a sustainability framework for carbon capture and storage systems: the result of interactive policy making in the Netherlands.
Prachi Singh Twente University	Structure and Activity Relationships for Amine Based CO2 Absorbents
Bart Terwel Leiden University	Just say what they expect you to say: the influences of argumentation on trust in organizations.
Rick van der Vaart TNO Science and Industry	Membrane Contactors for Post-Combustion CO2 Capture

Leiden University assessed informed and uninformed public opinions by an Information- Choice-Questionnaire and by a Traditional Questionnaire (N=333). In October 2005 a second Traditional Questionnaire was administered to a new sample (N=300). This TQ retest was done to replicate the results regarding uninformed "pseudo-opinions" on CCS technologies and to prove that these opinions are easily changed within minutes even by mood changes of respondents. Results will be presented at GHGT-8.
Leiden University also carried out studies on Trust. One study examined the influence of argumentation about CCS technologies on public trust in organizations. Another experimental study was performed about the influence of expertise and trustworthiness of communicators on the processing and acceptance of information about CCS. The results will be presented at GHGT-8.
KEMA published the second issue of the STACCATO Newsletter in July 2005 and the third issue in December 2005. This newsletter is aimed at informing the electricity producing sector on CATO issues.

Dissemination of knowledge
Internal CATO workshops have provided a wealth of information and promoted the exchange of information among the participants. A knowledge dissemination plan outlined the broad range of activities to undertake, including the maintenance of the website (www.co2-cato.nl), a national symposium on CCS and the production of newsletters and brochures. Scientific dissemination takes place via papers for scientific journals and presentations at conferences. In table 1 a non-conclusive list is presented of contributions to GHGT-8 that are (partly) accomplished by the CATO programme.