



Final (10 September 2007)

## MID-TERM REVIEW REPORT

The Mid-Term Review Committee consisted of the following members: Dr. Kelly Thambimuthu (chair), Mr. Nick Otter, Mr. Tony Espie, Mr. Pierre le Thiez, Mr. Walter Ruijgrok, Dr. Esther Luiten, Dr. David Reiner, and Dr. Bert Metz.

The review took place on 29<sup>th</sup> and 30<sup>th</sup> of August 2007, in Utrecht, the Netherlands. Because of other duties that week Dr. Metz carried out his part of the review one week earlier, i.e. on the 21<sup>st</sup> of August. He focused on CATO WP1 and his comments are integrated in this report.

### Policy Relevance

#### Present

CATO has developed into a successful research network in the Netherlands and has “de facto” become the Dutch national CCS program. It should be noted that this was not the original intention but through the nature of the activity, CATO has initiated numerous CCS projects in the Netherlands that are now highly relevant to the new national Dutch policy on climate change where CCS is recognised as an important element. CATO is therefore a ‘gift to government’ and has established a much needed basis of a national capability in CCS.

CATO is well linked to CCS research activities internationally and especially in Europe. It is one of the few national European CCS programs covering the entire CCS chain. The active participation of industry, research institutes universities and NGO’s makes CATO a powerful consortium which is similar in nature to the highly influential ZEP EU Technology Platform.

In light of the above, it is important that the present activities of CATO continue past the end of the program in 2008 and so allow it to continue to play a significant underpinning function in the emerging Dutch CO<sub>2</sub> reduction strategy in which CCS is set to play an increasing role.

#### Future

Continuity of CATO will be particularly important in light of the need for a skills base for the application of CCS in the Netherlands. It should, therefore, provide a focus for the CCS research and technology development and be complementary to other Dutch actions in energy efficiency and renewable energy sources.

Continuation of CATO will be essential in providing the necessary support to underpin the ability of the Netherlands to participate in the proposed European ZEP Flagship Program of up to twelve large-scale CCS demonstration projects.

The Review Team supports the proposal from the current CATO project to change the balance between basic R&D and applied research in the follow-up of CATO. There should be strong activity supporting implementation of first generation technology, but also still maintain clear activity towards the provision of second generation technologies and beyond.

To be able to support government policy, the follow-up of CATO program should be designed so that it can act in a flexible way towards addressing questions that arise in a changing policy environment.

It was noted by the Review Committee that the current program is already called CATO-1 and it took this as a welcome indication that the thinking is to have a follow-on CATO-2 initiative, even by parties outside the program, especially policymakers. This illustrates the quality of the current program and the need for a follow up. However it is recognised that there is room for improvement and that a lot of work needs to be done for an appropriately targeted new program. CATO-1 proved the value of a research-driven approach, but the changing policy environment and fast technical development require another approach of CATO-2. The Review Committee is of the view that it will be necessary to act quickly in the remaining term of CATO to ensure that the required continuity is established. To this end it is recommended that a proper facilitated team is established before the end of the year to make a proposal for a follow up. In so doing, CATO-2 should be structured in such a way that it is more flexible in anticipating changing requirements to facilitate real implementation of CCS technology.

Engagement of the full industrial and research chain needs to be achieved in any follow-up CATO action, the earlier the better in the planning process to ensure that the program meets overall strategic needs. The committee is therefore pleased with the contacts currently made with energy companies (NUON, Essent, EON), industry (Linde, Corus) and Dutch regions with ambition towards CCS, such as Energy Valley in the North and the Rotterdam Port area. These should be built upon, but reflection is also needed on possible cooperation with international CCS companies.

Emphasis on PhDs has played an important role in developing current and future capacity, but has limited the ability of the project team to respond flexibly and proactively to policy developments. Greater use of post-doctoral fellows and more senior researchers will allow those with greater ability and maturity to translate CATO's research into policy relevant information.

## **1. The scientific and other quality of the project**

### Scientific quality

The overall scientific quality of CATO is considered to be high. The policy to turn the research findings into papers for international journals has helped to ensure this scientific quality. The active involvement of CATO researchers in European cutting-edge projects can also be considered a proof of the high level of quality. Furthermore, the rate at which practical lessons are learned is noteworthy.

International and national embedding of the research program is pursued through linkage with other international and national research networks, programs and projects. This is achieved by the fact that CATO researchers and/or their institutes are actively involved in several programs, networks, and projects. Also research documents are shared via an Internet and Intranet application which helps both formal and informal interaction within the program. In a number of cases the links are clearly designed, but in other cases the links appear to be ad hoc rather than reflecting any clear prioritisation.

The social science program is currently focused on public perceptions based around a strong social psychology team. The quality of the work is very high and continued effort to publish in top journals should continue.

The CATO program, which combines most of the expertise of the Netherlands on CCS, has the opportunity to offer a “one-stop shop” for information on Dutch CCS activities. In order to play this role even better, it is recommended that the CATO working papers and published papers are made more easily accessible and be offered in a more consistent manner on the website.

#### Other qualities

The network building can certainly be mentioned as one of the strong points of the project. A Dutch expert community on CCS has been established. Another indication for the quality of the program is the interest of many other large parties for a follow-up of CATO.

Capacity building is not only done for the Dutch community, but also for the European and global community, given the fact that former CATO experts are now employed elsewhere in CCS programs.

The research in CATO is complementary to other national and European projects.

The approach of CATO to cover the whole CCS chain and to address the technical as well as the non-technical issues of CCS is regarded as a very beneficial attribute..

#### Future

The Review team recommends that a follow-up program addresses also regulatory and infrastructure issues that will be increasingly important in the deployment of CCS technology. Also the public perceptions effort is vital to understanding public acceptability and should be continued and expanded. Financial investment scenario calculations (taking into account available private and public resources) is also a topic that needs to be addressed.

The results are some of the most policy relevant and offer a clear point of interaction between government, industry, and non-governmental organizations. As implementation projects are proposed and developed, the role for assessment of public perceptions at the local level will be essential from the very earliest stages of a project.

## **2. Its substantive coherence**

### **General observations**

Informal contacts are an important aspect of the program to create coherence. This aspect could be strengthened even further. Being in different locations and data confidentiality issues do pose challenges. It is good that the WP leaders meet every three months to keep the progress going and to take care for the necessary interaction between work packages, but additional efforts should be made to share findings among participants and to create institutional mechanisms to foster collaboration. The existence of an overall Steering Committee and a Scientific Advisory Council also contributes to the coherence of the program. The current program is lacking an authoritative body that may redirect research priorities to improve coherence. It is recommended to formulate performance mile-stones that focus R&D for the next CATO program, rather than formulate deliverables (or research packages).

### **Storage**

The program correctly identifies the storage in gas fields as a key opportunity for the Netherlands. However given that the Groningen field will not be available until post 2050, it is recommended that saline formations should be added to a follow up of the program.

Two elements of the current program, mineralization and ECBM, may offer only niche opportunities for material reduction of CO<sub>2</sub> emissions. The proportion of the current budget which is allocated to these topics does not appear to be proportionate to their significance for reducing CO<sub>2</sub> emissions.

WP5 Monitoring would be enhanced by additional clarity of focus by separating technical development from risk assessment and regulatory issues.

## **Capture**

The more fundamental academic work in pre-combustion capture (e.g. in the field of hydrotalcites) at the Utrecht University is used as an input for the experimental work (e.g. in the field of SE-WGS) at ECN. This indicates a very positive and beneficial collaboration between the CATO partners. Also within the CATO project there is interaction between WP 2 Capture and other work packages. Similar trends are also noted in the coherence of fundamental and applied research in the post-combustion and oxyfuel capture areas.

The establishment of complementary projects shows that there is a very good coherence and interaction between research programs in the Netherlands.

This is also the case with external projects, especially the EU ones associated with EC Framework Programmes, where there has been a strong leverage for the Dutch capability and knowledge. This approach should be maintained within WP2.

## **System analysis and public perception**

WP1 is designed to play an integrating role in the CATO project. This role is implemented in a number of ways, with an emphasis on having researchers work in several work packages, informal consultation in designing the research and mutual inputs in the research reports. This is more important than the more formal integration through using outputs from other WP's as input in the WP1 work, since other WP's are only focussing on some aspects of CCS systems. It is recommended that more emphasis in reporting is given to the informal integration channels.

Within WP1 there are a number of closely related activities. This applies for instance to system integration in activity #4. It is recommended to clarify in the reporting how the different approaches in this activity are related and why different approaches are being used. Regarding activity #1 and #5 and WP6, it is observed that there is a lot of overlap in the research on stakeholder and general public perception. Although the various activities are distinct steps in building the complete picture, it is recommended to bring these activities more closely together, particularly when it comes to reporting the main findings.

The results of WP2 Capture and WP3 storage are being used in WP1. WP1 and the CATO participants more broadly such as industry and NGOs have had an important influence on WP6, for example in terms of moving the focus from stakeholders alone to the broader public. WP6 has helped in the design of questionnaires in WP1. The Review team is of the opinion that WP1 could have more influence on the research priorities of other WPs. This has to be taken into account formulating CATO-2.

Within CATO, there is evidence of information dissemination across work packages, diffusion of existing work and internal consultations, but little evidence of true collaboration. There is an enormous challenge in managing a large project across multiple institutions and disciplines that are geographically dispersed. Nevertheless, there is still a need for greater involvement and exchange between different disciplines. Besides the WP leader meetings four times a year, more ways could be sought to create knowledge sharing for true collaboration. The coordination and interaction between WP1 and WP6 should be further enhanced both in terms of reporting of outputs and the time available for coordination. There appears a willingness to engage in the time consuming process of coordination, but care should be taken to factor in such coordination explicitly in the design process.

## **3. The current relevance and predictive value of the chosen milestones**

### **General observations**

The relevance of CATO for government policy has become high. It is recommended to use opportunities to informing the public and political debate when issues attract attention. It would be useful to try and

produce timely and targeted pieces of information (neutrally formulated) to inform such a political debate. Provisions might have to be created in the program and management structure.

The work of the CATO program now already contributes to the creation of a strategy with fits into the European ZEP vision. For example, it could help to choose which type of demos should be done in the Netherlands in order to reach the ZEP objectives especially in relation to the proposed European Flagship Program for CCS demonstration at large scale.

It should be clear what the commitment is of government policy to CATO. Also what output should CATO provide to policy development. These answers should be clear in order to be sure that CATO addresses the key questions and relevant issues. There is a real opportunity to make the program even more policy relevant.

Goals of CATO and the Working Group Clean Fossil are similar, but the working method is different. WP1 and the CATO Steering Committee could support this external Working Group.

## **Storage**

### Subsurface mineralization

Subsurface mineralization has been shown by the project to play a minor role in reducing the mobility of CO<sub>2</sub> over the medium time frame. The committee supports therefore the refocusing of the program deliverables to work in fluid – caprock interactions.

### Surface mineralization

Surface mineralization is likely to have only niche applications. It would be useful to have a complete CO<sub>2</sub> balance for the mineralization process (LCA). Also it may be an idea to produce process flow sheets for large-scale applications. To conclude the study a life-cycle CO<sub>2</sub> and energy balance should be provided for the process.

### Monitoring, safety and regulations

The scope of this activity is very ambitious. There is a need for a clear separation between technical development and regulation, and for a top-down approach with a precise objective. A lot of work in seismic interpretation and modelling is done for coal seams (RECOPOL): there is a need for more research on simple media (e.g. sandstone). Activity on RA methodology should take into account the discussions on the role and applicability of this technique that are currently ongoing under the IEA GHG Program RA Network.

The technique development work for monitoring would be better separated into a new WP. The current work on cross-well seismic would be enhanced by using a simpler system e.g. sandstone brine system.

### ECBM

There is a lack of clarity about the scale of opportunity for storage of CO<sub>2</sub> offered by ECBM. Concerns include the potential for mining of coal after ECBM and/or underground coal gasification.

### Gas fields

Future demonstrations of seal integrity (geochemical and geomechanical effects) and well-bore integrity are key issues for gas fields. The significance of cooling on fluid and rocks properties should be quantified.

## **Capture**

The CATO objectives ‘efficiency improvement’ and ‘cost reduction’ are accepted widely throughout the global community as the key issues within CCS that need to be addressed. It is good that all fuels are covered within the different research projects. This way the right strategy is in place to deal with all vital issues. The expectations with regard to the outcome of CATO were high, and a follow-up is needed to achieve the ultimate efficiency improvement and cost-reduction goals. Niches are addressed quite well (e.g. research in SE-WGS).

The coherence between CATO program and other national and European projects is a strong point. The research has created a good basis for other (European) research projects and is thus leveraging new

projects (CACHET, CAPTECH). Also it has a spin-off to actual demo projects (Buggenum) and future CCS projects in the Netherlands such as the NUON Magnum project. The Review Committee appreciates that the experience and knowledge acquired within CATO addresses the whole chain from fundamental research to demo-phase.

It requires courage to actually stop certain research routes. It is appreciated that ECN will have a go-no go moments with respect to research in specific technologies, and this practice is also encouraged where relevant in the post-combustion and oxyfuel capture areas.

It is not certain if all the chosen capture technologies studied within CATO will actually be used at large scale in the future. However, at this stage it is agreed that a portfolio approach should be taken and so allow the research to build up knowledge that will be applicable to a wide range of application and across all CO<sub>2</sub> capture processes. It is recognised that it may be necessary to prioritise this in the future but at the present time it is likely that different technologies will be applied to different applications and so a broad capability in the Netherlands is required.

The Review Committee recommends tackling issues with respect to system integration and practical implications in follow-up projects (e.g. with respect to engineering, equipment).

### **System analysis and public perception**

The challenge of communicating with key stakeholders and with the broader public is recognized in Work Packages 1, 6 and 7. There is considerable and quite impressive effort in communicating internally and in documenting public understanding. Also there appears to be strong recognition of CATO in government circles and beyond. However, there can be more emphasis on dissemination of information beyond CATO in a systematic and professional way. For example, it can be made more clear how CATO fits into the policy process and how it should respond to policy initiatives; the engagement of WP leaders in the media can be increased; advice to policy-makers and interactions with media can be better documented; and the website, which is a useful internal communications tool, can be better designed for a broader audience. The Review team advises to set certain funding aside for these purposes and involve communication specialists.

The relevance for policy of WP1 (as a synthesising and research priority-setting tool of the CATO project) is potentially high. The performance on both aspects - synthesising and research priority-setting – can be improved. It is also recommended to better use the opportunities of informing the public and political debate when issues attract attention. Sufficient senior input in WP1 is required to inform political debate. Currently, WP1 relies too much on PhD students.

## **4. The relationship between progress and the project's mission/final objectives**

### **General observations**

In general the progress in the CATO program is regarded as being satisfactory.. The research is as pragmatic as it can be. Of course some of the ultimate goals cannot be reached in a research program of 5-year duration.

It should be noted that the mid-term review comes too late in the process to have much impact on the remaining one and a half years of the project.

Different actors have moved up a learning curve in terms of cooperation and understanding across work packages. Maintaining capacity, e.g., retaining PhDs as post-docs, is essential because of the links that have been established and the knowledge gained.

### **Storage**

The studies set out in the project proposal will be delivered. In a number of cases they should result in refocusing (e.g. subsurface mineralization) or termination (e.g. surface mineralization) of the work.

## **Capture**

The goals set in the project proposal (e.g. to deliver Proofs of Concept and pilot plants) will be achieved. In some cases additional funding was necessary, but the linkage to other projects (e.g. CAPTECH) has made this possible.

## **System analysis and public perception**

Progress in WP1 in general seems fine, though interaction and timing of the various activities within WP1 can be improved to create synergies in results of the various activities *within* WP1. There are some doubts that within WP1 continuity has been ensured by retaining information after staff members have left the program. WP6 outputs seem to have done well in meeting its goals by engaging with industry and NGO stakeholders and getting results taken up by the media and other key actors.

The project of Hoogwijk/Ecofys on development of a new energy system model for Europe is an important element. Unfortunately this activity started relatively late in the project and therefore there is a risk it will not be completed before the end of the project (although provisions have been made to use at least some elements of the new model to report relevant findings in time).

## **5. Implementation of changes recommended following earlier monitoring rounds**

On the basis of internal monitoring by SenterNovem in 2006 there has been a meeting with representatives of the Committee of Wise Men in early December 2006. In that meeting the Committee has recommended that the program has an independent chairman of the Steering Committee and adds external members to the Scientific Advisory Council.

Both measures have been implemented by the management of CATO, and are to the satisfaction of the Mid Term Review committee. Also the delays in producing certain deliverables have been properly addressed.

## **6. Vision and strategy for the future of the project after the grant period ends (in terms of the embedding of knowledge, organisation and finance)**

### Scope for CATO-2

The topics which are being addressed by the CATO program are consistent with those being carried out internationally and especially in Europe by the ZEP European Technology Platform. It is recommended that a follow-up of CATO continues to address these topics, and that they should be supplemented by issues underpinning CCS large-scale demonstration, infrastructure, and regulation.

The CATO actions undertaken to date have been very complementary with those of Europe, especially in connection with the EC Framework Program on Energy. CATO is therefore contributing to the provision of high quality research facilities and appropriately trained scientists and engineers nationally and in Europe. It is recommended that this approach is continued and so take advantage of and leverage funding. It is suggested to ensure that any future activity under CATO addresses the twin need of continuing to develop 'next generation' capture technologies and to support the commercialisation of existing available (1<sup>st</sup> generation) capture technology.

CATO-2 could support the establishment of the two major projects (which will happen in five years time) with scientific and technical expertise. In the meantime the program can play a facilitating role in setting up the pilots and small demos that are needed before that time.

It is recommended to integrate several current research projects into the continuation of a future CATO-2 program.

Political, regulatory and legal analysis is largely absent in the CATO project and it will be essential to include these approaches in CATO-2.

Regardless of the level of participation of NGOs in the overall CATO-2 program, it is especially important that the full spectrum of NGOs plays a role in the future of WP1/WP6 to be able to properly reflect their concerns and engage with all key stakeholders in the Netherlands.

### Capacity building

CATO has been very successful in training a large cadre of PhDs in science, engineering and the social sciences. Looking forward, there is a need for more post-doctoral researchers to offer the best PhD students a way to continue their research, to increase the academic output, and to allow for greater flexibility in the program to respond to a changing environment in a policy and technically relevant manner.

CATO-2 can also play a role in retaining CATO researchers with their CCS expertise by offering them prospects of careers in the field.

Expertise is needed in key technical disciplines (e.g. engineering) and sufficient supply is needed if CCS grows to become a major element in the Dutch and European energy sector. CATO-2 should think about how it can contribute to building this expertise.

### Process

Engagement with the industry and power sector in an early phase of the CATO-2 program for the development of 1st and 2nd generation capture power plants is of utmost importance. To aid this engagement it is recommended that a study should be undertaken that to characterise the strengths and resources of the Dutch industry that relates to CCS.

At the beginning, CATO was necessarily a largely bottom-up driven process with the advantage that it could attract the best people to work on the project. To improve coherence and relevance, the Review team advises to move towards a more top-down approach. A top-down approach could also help in defining precise objectives (e.g., R&D objectives needed for the preparation of a storage pilot). However, attention should be paid not to lose the advantages of the bottom-up approach that is valuable to building technical competencies and capacity.

### Timing

The work plan of a CATO-2 must be tuned to the CCS developments in the Netherlands (e.g. the timing of the 1st large scale project which is expected to be around 2014-2015).

Because CATO formally ends in December 2008, there is a pressing question on the timescale for the renewal of the program, the assurance and level of funding for CATO-2. Under the current proposal there is some concern that CATO-2 may become too reliant on industry. CATO-2 should take care to not move too close to supporting implementation of large, commercial-scale projects because of concerns over the timing of major projects. It will be necessary to also maintain a strong R&D element addressing second generation technologies and beyond. However such activity should remain focussed on issues that will facilitate the deployment of CCS technologies (e.g. cost reduction, system improvement and safety of storage).