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# Global Technology Roadmap for CCS in Industry

Roadmap Review Workshop Report

**24th September, 2010**
**Amsterdam, the Netherlands**

UNITED NATIONS
INDUSTRIAL DEVELOPMENT ORGANIZATION

ROADMAP REVIEW WORKSHOP REPORT

# Global Technology Roadmap for CCS in Industry

prepared by

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## Project Funders:

The principal responsibility of the Ministry of Petroleum and Energy is to achieve a coordinated and integrated energy policy for Norway. The Ministry is responsible for CCS matters.

The Global Carbon Capture and Storage Institute is a bold new initiative aimed at accelerating the worldwide commercial deployment of at-scale CCS.

## Partners:

The IEA is an intergovernmental organization which acts as energy policy advisor to 28 member countries in their effort to ensure reliable, affordable and clean energy for their citizens.

The IEA GHG is an international collaborative research programme focusing its efforts on studying technologies to reduce greenhouse gas emissions.

## Host:

Shell is a global group of energy and petrochemicals companies with around 101,000 employees in more than 90 countries and territories.

UNITED NATIONS INDUSTRIAL DEVELOPMENT ORGANIZATION
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## 1. The Global Technology Roadmap on CCS in Industry

In February 2010, a project was launched to develop a global technology roadmap on carbon capture and storage applications in industry. CCS is generally associated with applications in the power sector, however there are potential opportunities to deploy the same basic fundamental technologies in many of the world's largest industrial sectors. Critically, there still remain significant knowledge gaps in moving towards commercial implementation of carbon capture and storage, especially in industry. The roadmap will explore the technical details, deployment potential and specific policy and regulatory aspects of CCS deployment in industry, while simultaneously raising the awareness of the subject.

Initiated by the United Nations Industrial Development Organization (UNIDO), the project is supported by the Norwegian Ministry of Petroleum and Energy and the Global Carbon Capture and Storage (CCS) Institute. The International Energy Agency secretariat and the IEA Greenhouse Gas Implementing Agreement are partners in this activity. The project will draw from the methodologies and experience of the partners in technology foresight and road-mapping, and provide relevant stakeholders with a vision of industrial carbon capture and storage up to 2050. It will have a focus on developing countries with energy intensive industries, and aim to inform policymakers and investors about the potential of such technologies. The roadmap is due for completion by Spring 2011.

As part of the project, three workshops will be organized. This document serves as the report of the second workshop in Amsterdam, which congregated an international group of industry representatives and experts.

## 2. Objective of the meeting

The goal of the meeting was to gather further input for improving and advancing the roadmap. Prior to the meeting, five sectoral assessments and a zero-order draft roadmap was distributed to the selected participants. The participants included a mix of representatives from industry, governmental and non-governmental organizations, from both developed and developing countries (the participants list can be found in Annex 2). Specifically, the workshop had been arranged to:

- Highlight issues such as data availability and data variables experienced by the roadmap authors, and collect input on possible ways forward
- Discuss a number of selected topics that are to be covered extensively in the final roadmap document, such as business models for CCS in industry, source/sink matching and the identification of concrete early opportunities for CCS in developing countries
- Gather feedback on the draft roadmap document

The opening session presentations were given by representatives of the project implementing agency (UNIDO), the meeting hosts (Shell), the project sponsors (the GCCSI and the Norwegian Ministry of Petroleum and Energy) and the lead consultants (ECN) (section 3). The remainder of the meeting was organised into two sets of three parallel breakout sessions, covering six selected topics of discussion (section 4) and a feedback session (section 5). The meeting agenda can be found in Annex 1. Section 6 of this report discussed the next steps.

## 3. Opening session

After the opening of the meeting by Dolf Gielen (Chief - Industrial Energy Efficiency at UNIDO), Wilfried Maas (Shell Amsterdam) welcomed the participants on behalf of the Shell Research and Technology Centre in Amsterdam. Mr. Maas explained the activities taking place on the Shell premises, the features of the new building and the urban development taking place around the premises.

Tim Bertels, Shell's CCS Projects Portfolio Manager, presented Shell's extensive CCS activities and experiences. To continue meeting the world's growing energy demand, while reducing greenhouse gas (GHG) emissions, several pathways must be pursued. CCS is one of the key pathways that Shell is progressing along with energy efficiency, low $CO_2$ fuel options, and advocating more effective $CO_2$ regulations to reduce global GHGs. Shell's CCS project portfolio includes industrial scale projects in development, including involvement in the Mongstad refinery project planned for 2014 in Norway, the Quest Athabasca oil sands project in Canada planned for 2015, and the Gorgon Liquefied Natural Gas Project planned for 2014 in Australia.

Bob Pegler, Senior Vice President of the GCCSI, briefly reinstated that the objectives of the Global Carbon Capture and Storage Institute (GCCSI) are to remove barriers forthe deployment of CCS, to provide advice and knowledge, and to influence governments, industry and CCS stakeholders. The GCCSI aims to encourage CCS demonstration projects. A 'balanced portfolio' is needed of CCS demonstrations in developing and developed countries, and in the power sector and industry.

Kristoffer Stabrun of the Climate, Industry and Technology Department of the Norwegian Ministry of Petroleum and Energy reiterated the need for increased attention for CCS demonstrations in industry, and highlighted that $CO_2$ has been injected in the Sleipner and Snøhvit fields in Norway successfully for a number of years, to a large degree thanks to a tax on $CO_2$ emissions. The Norwegian government is committed to developing CCS on a large scale, and the total public spending on CCS in 2009-2010 combined was approximately US$800 million.

Dolf Gielen then introduced the Global Technology Roadmap on CCS from industrial $CO_2$ sources project and the main objectives of the roadmap. Industry accounts for approximately 40% of total energy-related $CO_2$ emissions. The majority of industrial energy use takes place in developing countries, and the involvement of such countries in technological development is important. In certain industrial sectors, such as the cement sector, CCS is the only way to significantly reduce $CO_2$ emissions. However so far, the majority of attention has been devoted to CCS deployment within the power sector.

Since the beginning of the roadmap project in February 2010, assessments of the potential for CCS in the cement, iron and steel, refinery, biomass-based and high-purity (including natural gas, hydrogen production and coal-to-liquids) industrial sectors have been commissioned and completed. An initial two day workshop has taken place in Abu Dhabi on June 30$^{th}$ to August 1$^{st}$, hosted by MASDAR, involving a technology scoping exercise for the industrial sectors covered. The information provided in the sector assessments have been incorporated in a draft roadmap that has recently be released. Furthermore, it has been deemed necessary to commission two further studies to support the roadmap, providing greater detail on source-sink matching and the possibilities for $CO_2$ enhanced oil recovery in developing countries. Although it is not expected that the final roadmap will be available in time for the 16$^{th}$ Conference of the Parties (COP) to the United Nations Framework on Climate Change

Conference (UNFCCC) in Cancún, Mexico starting at the end of November 2010, a technical synthesis report and a short policy document summarizing the key roadmap messages is likely to be released for COP16.

The final presentation of the opening session was made by the principal consultant of the roadmap, Heleen de Coninck (Energy research Centre of the Netherlands). A roadmap is actionable, and should provide an agenda to act for government, industry and the financial sector. The progress through a roadmap can be measured by defining milestones to be reached, for example, a certain number of CCS demonstrations in industry by a specific point in time. De Coninck explained that it turned out more difficult than expected to distil consistent, comparable data from the different sectors covered in the roadmap, including projections to 2050, and recent emissions data for certain sectors. In addition, for some sectors, cost data are commercially sensitive and hard to get by. This is one of the reasons why more time is allocated for making a technological synthesis report. The data did not allow for the immediate translation of the sectoral assessments to a full and actionable roadmap. However, the Roadmap process has already raised the interest of industry and government for CCS in industrial sources, and has already led to higher awareness in developing countries.

Ms. de Coninck explained that the aim of this meeting was initially only to collect input on the current, zero-order draft roadmap. In addition to that, this meeting should facilitate the exchange of information on the different sectors, and it should help to collect more information on those sectors.

## 4. Breakout groups

During the meeting, two rounds of three parallel breakout sessions took place, lasting roughly 1.5 hours each. Each breakout sessions was appointed a moderator (in brackets):

1a) Technology characterization (Chaired by Dolf Gielen)
b) Business models for CCS in industry, including EOR (Chaired by Wilfried Maas )
c) Bringing industrial CCS higher on the global agenda, and engaging developing countries and economies in transition (Chaired by Bob Pegler)

2a) Actions and milestones (Chaired by Kristoffer Stabrun and Bob Pegler)
b) Matching sources and sinks (Chaired by Mohammad Abuzahra, IEAGHG)
c) Identification of early opportunity projects (Chaired by Nathalie Trudeau, IEA)

The participants were asked to choose which session reflected the interests and expertise. Minutes of each breakout session can be found below.

### 4.1. Technology characterization

This session focused on the technology and data scope of the sectoral assessments, the technology synthesis report, and eventually the roadmap. The discussion focused on two key questions: what are the essential technologies to be included under the sectors, and what key variables affect CCS cost numbers?

The rationale for this session was that the data on the various sectors, for current emissions, projections and/or costs, were found to be highly variable and sometimes inconsistent. It was

the aim of this particular breakout session to agree a list of technologies and identify the references for these technologies.

*Data variables*
Utilizing a set of common metrics for the CCS cost data for each of the individual industrial sectors was considered the best approach. Issues exist in choosing the most suitable reference to compare a industrial installation with CCS. For example, in the iron and steel industry, if you move from a blast furnace to a DRI process with capture, is the reference case a blast furnace without CCS or a DRI installation without capture? Further complications were also highlighted including the differences in global energy prices, average plant sizes and a suitable discount rate to use in economic assessments. Setting a consistent discount rate, or use of a typical commercial rate for a number of regions was recommended by participants. A sensitivity analysis could be conducted using different discount rates, however this was considered impractical given the amount of data and time restrictions.

It was discussed that by presenting both annualized costs, and upfront investment cost for CCS, the roadmap would be useful for both industry and policy makers. It was also recommended that the costs for CCS could be presented as a cost of an industrial product, cement for example, produced in a plant with and without capture. However, it was agreed that industry may not be so forthcoming with basic manufacturing costs.

*Technology selection*
It was raised by members of the cement industry that carbonate looping is a potential abatement option for the industry, and should receive attention in the roadmap.

For refineries, $CO_2$ capture from onsite hydrogen production plants would be the lowest-cost option to deploy CCS in the refining sector. The next-lowest cost was likely to be a fluid catalytic cracker (FCC) combined with oxyfuel technology. In addition, post or pre-combustion CCS could be applied to refinery plant utilities. Pre-combustion at utilities could unlock the potential for polygeneration, and the use of biomass.

Finally it was stressed that contrary to common assumptions, modern hydrogen manufacture does not typically result in high-purity $CO_2$ off-gases. However, the concentrations would be higher than those of $CO_2$ in coal or gas combustion exhausts.

### 4.2. Business models for CCS in industry, including EOR

The draft roadmap/technology synthesis report currently mentions four potential business models through which CCS from industrial $CO_2$ sources could become viable: industrial CCS projects with $CO_2$-EOR, certain industrial agglomerations, BP's Decarbonised Fuel projects, and oxyfuel in cement and steel. The discussion in the breakout group focussed primarily at possibilities for enhanced oil recovery, as being the low-hanging fruit in combination with industrial sources, and further on how storage providers and $CO_2$-emitting industries collaborate, how financing and investments can be enticed towards CCS, on sharing infrastructures, and on for which industries CCS is a cost only.

The group discussed EOR issues at length, and briefly also other revenue-generating options: Enhanced Coal Bed Methane and Enhanced Gas Recovery. $CO_2$-EOR can be a "leading-in" technology, as there is not enough potential to store all needed $CO_2$ emissions in EOR operations or even depleted oil fields (without EOR). The economic viability of $CO_2$-EOR depends on many factors: the reservoir specifics, the capture cost of $CO_2$ are both very important. In Indonesia, there are examples where cost recovery is not sufficient. In addition,

$CO_2$-EOR has a distinct time window in the reservoir lifetime. All current $CO_2$-EOR activities are onshore, experience needs to be gained offshore, R&D needs to take place to evaluate potential environmental impacts Regulation might need to be developed. It was also suggested that abandonment of oil recovery operations might have to be delayed in order to allow for $CO_2$ storage.

The need to help storage providers with a commercial model for CCS was emphasised. One of the potential models that was mentioned was that of $CO_2$ becoming an in-demand commodity to store, by providing a subsidy on storing $CO_2$. Storage providers, potentially oil and gas companies who already have much underground capabilities, will then source suppliers of affordable $CO_2$. Also, regulation on post-liability transfer and help with overcoming demonstration barriers is needed.

Policy to incentivise CCS needs to be in line with what investors and finance providers want to see to make CCS projects "bankable". For this, the CCS community could learn from the renewable energy sector, as another sector with high upfront investment costs. A price on $CO_2$ or equivalent policy is a first condition as CCS, in by far most cases, is not economically viable.

A potential business case for CCS in industrial sources might be by sharing infrastructures and making use of industrial agglomerations. The Rotterdam Climate Initiative in the Rotterdam Harbour is a potential example of that. In certain specific areas, sharing infrastructure for transport and storage can make the business case for CCS more viable. It was recommended that the Roadmap looks for those areas and should attempt to make companies in such agglomerations aware of CCS.

### 4.3. Bringing industrial CCS higher on the global agenda, and engaging developing countries and economies in transition

The session reviewed the general understanding of the role of CCS in the global agenda and the motivation and actions needed to engage developing countries and economies in transition

While identifying the reasons why most attention to CCS goes to capture from the power sector, as shown at the GHGT10 conference during which only one session was dedicated to CCS applications in industry, the following reasons were identified:

- a lack of climate commitments or concern for domestic mitigation actions prevents developing countries from considering certain technologies
- the fact that the current terminology/ language used for CCS promotion is structured by the power sector. The challenge for developing countries is that power generation is a domestic based sector, so it cannot attain the direct benefit from being carbon neutral in countries in which no mitigation target or regulations are in place. Moreover, most developing countries do not consider CCS as a competitor mitigation measure for renewable energy sources for $CO_2$ mitigation.
- Discussion in developing countries are of an academic or technical nature and have yet to mature into considering CCS as a business proposition.

The direct actions identified in order to raise the profile of CCS in industry higher on the scientific, industry and policy agenda are not easy to achieve and mainly depend on political decisions at country level. However, the following measures were discussed as actions that may trigger the interest of policymakers and decision makers:

- Involving global actors in the promotion of CCS for industry such as multilateral banks and international companies which may disseminate their knowledge and experience in countries in which national stakeholders are unaware or not engaged in the progress of CCS. For example, some Multilateral Development Banks have raised awareness of CCS when requiring that new power generation units must capture ready in order to be financed.
- Identifying sources for funding for early stage development (R&D), and also promote capacity building in institutions which may become instrumental for development of CCS as a business such as financial institutions providing finance.

The main action to be taken to seize the attention of countries to CCS is raising the discussion level, by promoting a policy path which involves first defining Climate Change policies at national level tailored to the capabilities and needs, followed by identifying the need for domestic mitigation actions and finally by promoting technical measures amongst which CCS should be included.

With regards to the international community engaging developing countries and economies in transition, it was suggested that advocacy should be done for CCS as a single technology rather than differentiating industrial and power generation applications. More coordination amongst existing CCS initiatives should be achieved to prevent overwhelming developing country governments, a phenomenon defined as "CCS fatigue".

Finally, when defining which countries should be addressed first it was recognised that CCs priorities should consider the following criteria:

- ✓ Time and impact – where take up may occur faster
- ✓ Regions where there is interest and CCS will be part of the mix
- ✓ Countries which could serve as role models for regions

### 4.4. Actions and milestones

The sectoral assessments as well as the draft roadmap/technology synthesis report and the Abu Dhabi meeting report talk about gaps and barriers to CCS in industry, and identify a number of actions and milestones. Some of those actions and milestones were reviewed in this session. It was suggested to focus in particular on policy actions and milestones, as at the moment, the lack of a policy framework seems to be the area where most barriers arise. The participants identified governments as main actorsto undertake policy action, but as Copenhagen has delivered little concrete outcomes, the general opinion among the participants was not optimistic. It seemed there was little appetite for industry leadership, although the meeting did acknowledge that in the absence of a strong global framework, this might be necessary to keep CCS moving.

A long list of policy actions was discussed, including specific ones aimed at the early opportunities for CCS, such as a "zero-venting" policy for $CO_2$ from natural gas operations and specific stimulation of using $CO_2$ EOR possibilities for storage. The World Bank and other multilateral banks should start incorporating CCS in their portfolios, and should pay attention to CCS-readiness. Although a global roadmap on CCS in industrial sectors was seen as a good step, regional or technology-specific roadmaps are needed as a next step. Multilateral funding, possibly through the Copenhagen Accord mechanisms or multilateral banks, were considered to play a role in constructing those roadmaps – and following up in real projects.

For CCS in industrial sectors specifically, it was suggested that an official statement (e.g. by the G20) would help bringing it higher on the agenda. This could release much-needed funding for demonstrations.

### 4.5. Matching sources and sinks

The spatial distribution of current sources of $CO_2$ in industry is relatively well-known. The storage potential is surrounded with more uncertainty. The future developments of $CO_2$ sources in industry is also highly uncertain, despite the fact that the general perception is that matching is driven by storage rather than sources.

There is need define the capacity and type of reservoirs available as sinks and that this activity should be done as early as possible in the development of a CCC project. Participants form the oil and gas sectors stated that even in depleted oil field it takes need 5 to 8 years for testing / risk analysis before injecting. Participants proposed to prioritise opportunities for early stage development even with limited data available.

When considering the technical aspects, participants recognised the need for defining guidelines for the technical considerations of sinks, including their suitability, eligibility and testing required for validation. Matching of sources and sinks must be done considering three dimensions: general capacity of sink over its lifetime, annual volume that the sink may uptake and time match of source and sink. Minimum guidelines were also recommended for specification of gas to be injected, mainly its composition, such as oxygen levels, sour gas and water content. Finally, in term of $CO_2$ transport, participants were confident that there is sufficient knowledge on the technology and its costs.

Regarding policy issues, global regulations need to be considered, in particular cross-border issues. From example, concerns were raised regarding the London protocol amendment allowing $CO_2$ transport, that has not yet entered into force (only Norway has ratified). At the same time, participants indicated that $CO_2$ has been shipped for 30 years .

Participants raised public perception as a key issue since the public is largely unaware of CCS, especially in developing countries. They suggested that the roadmap could serve as a tool for communicating, and proposed that communication strategy should be defined. Such a strategy should explicitly consider local culture.

### 4.6. Identification of early opportunity projects

This is the most practical session, focused or real industry possibilities. The aim is to identify some 50 “lighthouse” of projects in developing countries, that are as economically and environmentally attractive as possible, and that could be funded – by business, national governments or international funding mechanisms. The idea is to get as far as possible with concrete project ideas in developing countries that can serve as a to-do list in the eventual roadmap.

The session began by discussing whether a criteria was necessary for selecting developing countries where early opportunities exist. It was agreed to use a definition of early opportunities as defined by the IPCC “as projects that [are likely to] “involve $CO_2$ captured from a high-purity, low-cost source, the transport of $CO_2$ over distances of less than 50 km, coupled with $CO_2$ storage in a value-added application such as EOR.”

Beyond the purely technical aspects of CCS, for example the availability of highly-concentrated $CO_2$ streams with close proximity to suitable storage sites, a number of additional points of consideration were raised. The willingness of a developing country to engage in CCS, the existence of policies relating to CCS, and the relevant capacity in both regulation and engineering were highlighted as important criteria. The selection of the country requires diligence, given the political sensitivities of $CO_2$ mitigation activities in developing countries. Ideally, the project would be located where it would reduce the most $CO_2$ emissions, however this may not be possible given the constraints and considerations listed above. It was raised that the selection of a CCS project site would preferably be made in an area with further CCS potential, anticipating that knowledge and capacity would be developed through an initial venture, although this was not considered essential given the uncertainty of funding or incentives for additional projects.

Specifically, a number of potentially suitable locations for CCS projects in developing countries were mentioned. Namely:

- The Recôncavo basin, Brazil. Petrobras have been injecting $CO_2$ for the purposes of EOR into a number of oil fields in this basin for 24 years. At present the EOR activities are relatively small scale at approximately 120 tonnes $CO_2$ per day, collected from an ammonia plant and an ethylene oxide production facility. Petrobras are also investigating $CO_2$ storage potential in a saline acquifer, which could be as high as 4000 tonnes per day. There are ideas to collect $CO_2$ from planned installations in the area, such as a gasification plant which could provide up to 1.3 $MtCO_2$/yr for EOR and geological storage. However, the project is restricted due to difficulty in attaining capital.
- Daqing and Jilin oilfields and saline aquifers of the Songliao basin, China. Originally investigated under the 'Near Zero Emission Coal Project', a joint project between the EU and China. This project has been in operation since 2006, but could be scaled up.
- Other less concrete opportunities exist in areas where enhanced oil recovery already takes place, however $CO_2$ could replace other injection gases such as nitrogen (Cantarell oil field, Mexico) and natural gas (many parts of the Persian Gulf).

Iran is a developing country with an interest in CCS. An extensive inventory of $CO_2$ sources was available within the country, and that the identification of high-purity $CO_2$ sources for example from natural gas processing would be possible. In the Southern region of Iran, examples were provided of natural gas processing installations that emit approximately 1Mt of high-purity (>96%) $CO_2$ per year. In addition, the country has significant engineering expertise. However the deployment of CCS in Iran faces challenges such as a lack of capacity for extensive geological monitoring, and difficulties in acquiring compressors due to international sanctions against the country.

A brief discussion regarding the access to international funding mechanisms, such as the Global Environment Facility (GEF), and upon what conditions funding would be granted for a CCS demonstration project.

## 5. Synthesis session

The synthesis session was intended to disseminate the key points of each of the breakout sessions to all the participants, and to discuss the outcomes. A rapporteur from each of the breakout sessions held a short presentation (slides in Annex 4). A number of questions were

raised during the final presentations, which prompted discussion on possible policy approaches for CCS in the industrial sectors.

Leading in the discussions was the notion that with the weak signal from the Copenhagen Accord for emission reductions, CCS, including in industrial sectors, is unlikely to benefit from a global policy framework. Although in several developed countries, incentives are in place for CCS, most of these are for CCS in the power sector, and economic incentives for even low-cost CCS in developing countries is fully absent.

In trade-sensitive sectors, such as the iron and steel industry and refineries, carbon leakage is an important consideration. Alternative regulation for such sectors could be based on the carbon intensity of industrial products. It was suggested that this carbon intensity could be used as a basis for border-tax adjustments or sectoral agreements in which standards or best available technology could be enforced.

## 6. Next steps

For the roadmap project, the likely next steps are:

- Finalising the sectoral assessments where still needed (October 2010)
- Conducting two more studies: on Enhanced Oil Recovery and on matching sources and sinks (November 2010)
- Constructing a technology synthesis report from the sectoral assessment and complementary data (November 2010)
- Based on the technology synthesis report, write a four-page policy summary, to be finalized (and perhaps presented) at COP16 (December 2010)
- Use the dynamic around the Roadmap to process to identify potential projects and specifically engage relevant governments, companies and financers for such projects to realize those possibilities (continuous).
- Another meeting to discuss the roadmap document (tentatively scheduled for February 2011)
- Publication of the Global Technology Roadmap on CCS in industrial sources (Spring 2011)

## 7. Acknowledgements

This meeting would not have been possible without the generous support of Royal Dutch Shell. In addition, the support from the project sponsors, GCCSI and the Norwegian Ministry for Energy and Petroleum, is greatly appreciated.

## Annexes

Annex 1: Annotated agenda

Annex 2: Participants list

Annex 3: Introductory presentations

Annex 4: Break Group Session summary presentations

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