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Global Technology Roadmap for CCS in Industry

Policy Workshop Report

7th and 8th April 2011
Rio de Janeiro, Brazil
Petrobras Research Centre, CENPES
(Centro de Pesquisa e Desenvolvimento Leopoldo A Miguez de Mello)

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Global Technology Roadmap for CCS in Industry

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Policy Workshop

7 April – 8 April 2011
Rio de Janeiro, Brazil

Project Funders:

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

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.

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.

Workshop Sponsors:

The Department of Energy and Climate Change (DECC) has the responsibility to coordinate energy and related climate change issues in the United Kingdom.

Petrobras is an energy company leader in the Brazilian oil industry and among the top five integrated energy companies in the world.

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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 the industrial sector. 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 high-purity industrial sources of CO_2, cement, iron and steel, refineries and biomass-based industrial sources of CO_2. Simultaneously, the roadmap aims to raise the awareness of the subject.

Initiated by the United Nations Industrial Development Organization (UNIDO) and the International Energy Agency (IEA), the EUR 500,000 project is supported by the Norwegian Ministry of Petroleum and Energy and the Global Carbon Capture and Storage (CCS) Institute. The partners of the project include IEA Greenhouse Gas R&D Programme. Based on the required deployment requirements of CCS to meet the emission reductions foreseen in the IEA's BLUE Map scenario, the roadmap will 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 fall of 2011.

As part of the project, three workshops have been organized, the first in Abu Dhabi (June, 2010), then Amsterdam (September, 2010). This document serves as the report of the third workshop held on the 7th and 8th April 2011 in Rio de Janeiro, which congregated an international group of industry representatives and experts.

2. Workshop objective

The previous workshops held in Abu Dhabi and Amsterdam, explored the technical potential for CCS in the key sectors, and the relevant policy and regulatory aspects of CCS in industry respectively. Whereas the preceding meetings acted as scoping and fact-finding workshops upon which the roadmap could be tailored to meet the needs of important stakeholders, with the draft key messages available to the audience, the third workshop in Brazil acted as an important evaluation component of the iterative roadmap process. The final workshop in the technology roadmap process aimed to review the main policy and business recommendations, as well as actions and milestones. In addition, it provided a forum to discuss CCS in industry related issues in Brazil and Latin America.

3. Introductory messages from the host and sponsors

Operating in 28 countries, Petrobras is a global oil, gas and energy provider, headquartered in Rio de Janeiro. In 2009, the semi-public company achieved a net operational income of $US 91 billion, producing approximately 2.5 million barrels of oil per day. The company also operates 15 oil refining complexes, and almost 6000 refuelling stations in Brazil. The company has adopted a technology strategy with three primary focal points; improving and expanding production, diversifying its product portfolio and improving sustainability. The management of CO_2 from the company's processes is regarded as important to the meeting the latter goal, and significant research and development has been committed to the development of CCS.

The Global CCS Institute aims to accelerate the deployment of CCS across the globe by connecting parties to produce and share knowledge on the subject. The Institute has three main focal points, sharing knowledge, fact-based advocacy and assisting projects. Funded by the Australian government, the Institute now has 302 members (as of March, 2011), accounting for 80% of the world's CO_2 emissions from energy and industrial sources. In March 2011, the Institute released a report entitled the 'Global Status of CCS: 2010', which provides details on all the active and planned CCS projects. From this report it is clear that industrial CCS projects are underrepresented in the global portfolio of demonstration projects.

4. Introduction to the roadmap and results

UNIDO recognises CCS as a technology to reduce greenhouse gas emissions from industry. Therefore, in partnership with the IEA, in 2010 the roadmap process began with the aim:

> *"To advance the global uptake of low-carbon technologies in industry, whilst involving developing countries and transition economies, by developing a Global Technology Roadmap for CCS in Industry and to build the analytical foundation allowing to identify early opportunities for pilot/demonstration projects."*

As a part of the roadmap process, a number of sectoral studies have been produced, focusing on the potential for CCS in the specific industrial sectors of iron and steel, cement, biomass-based sources, oil refineries and a range of high-purity CO_2 sources. Furthermore, two additional studies have been conducted on global source-sinking matching for industrial sources, and also the combination of industrial sources with enhanced oil recovery (EOR). As previously mentioned, this meeting in Brazil was the third workshop, following earlier roadmap workshops in Abu Dhabi (June 2010) and Amsterdam (September, 2010). The publication and launch of the roadmap is expected to take place in the autumn of 2011.

4.1. Modeling results

The results from the IEA model used to generate the projections of CCS in industry to 2050 are consistent with the IEA BLUE Map scenario, using 2008 baseline data, which identifies the lowest cost portfolio of technologies to achieve a stabilization of atmospheric greenhouse gas emissions to 450 ppm CO_2-eq by 2050. In order to achieve this goal, between 2010 and 2050, 57 Gt of CO_2 must be abated, of which 19% should be reduced through the deployment of CCS, almost half of this deployment must take place in industry. In 2009, the IEA produced the Technology Roadmap for CCS (IEA, 2009), which provided projections for the deployment of CCS in both the power and industrial sectors, and outlined the financial, regulatory and policy milestones to achieve them.

The publication of another roadmap focusing on industry is needed because the potential for CCS goes beyond "clean-coal" in the power sector. Indeed, with 50% of the deployment of CCS required to take place in industry, the diversity of the various sectors warrants the provision of specific technological and policy action and milestones to the relevant stakeholders.

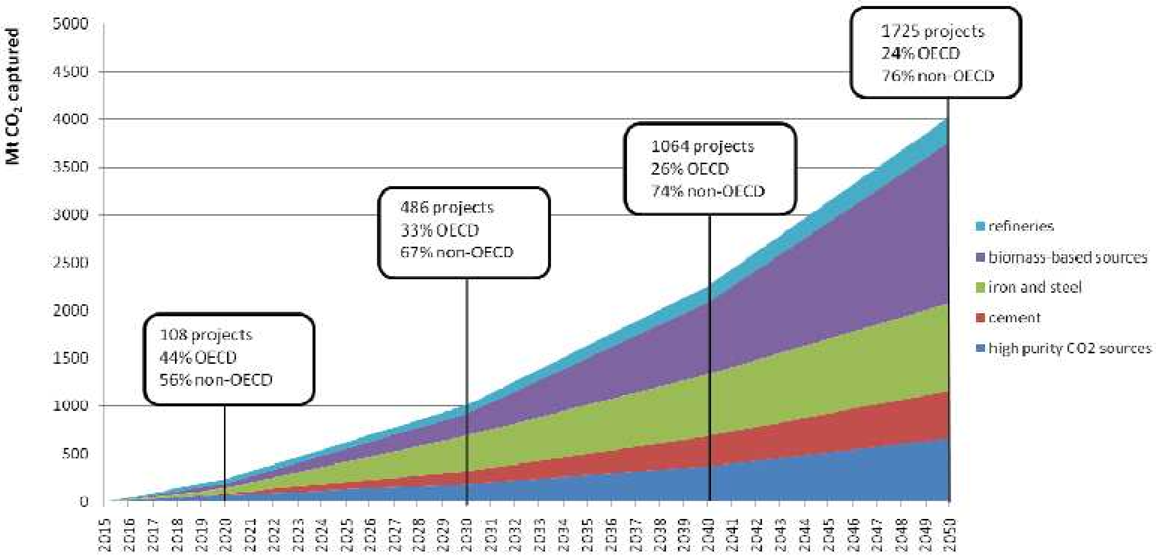

Figure 1: CCS potential to 2050 in the selected subsectors

The initial modeling results, which must still be finalized, indicate that 1725 CCS projects in industry are required in order to abate approximately 4000 Mt per year by 2050. To achieve the significant emission reduction required, the deployment of CCS in the biomass sector, such as in biofuel production, must be rapidly accelerated. The additional global investment costs required to reach such an ambitious deployment levels of CCS in industry, are expected to be US$ 1634 billion between 2010 and 2050. Refining of these initial modeling results are expected to provide greater detail on the number of projects needed in each individual sector, and the related investment costs.

4.2. Preliminary outcomes of the Roadmap

A roadmap is actionable and should provide a set of actions for government and industry. The Roadmap also contains milestones in order to measure the progress towards the final goal. During the process of drafting the roadmap, it has become evident that the heterogeneity of industrial processes means that post-combustion, pre-combustion and oxyfuel technologies must all be considered. The table below contains the sectors and the various capture technologies that have been investigated:

Sector	Production process	Capture technology
High-purity industrial sources	Natural gas processing (onshore/offshore)	Existing industrial gas separation techniques[1]
	Coal-to-liquids (CtL)	
	Ethylene oxide production	
	Ammonia production	
Iron and steel	Blast furnace (pig iron)	Top gas recycling (TGR) or oxyfuel blast furnace
	Direct reduction of iron (DRI)	Pre combustion (gasification) + Pressure Swing Absorption (PSA), Vacuum PSA (VPSA) or chemical absorption
	FINEX technologies	PSA[2]
	The HIsarna process	PSA or VPSA
Cement	Kiln/calcination	Post combustion technology using chemical solvents or oxyfuel technology
Refineries	Hydrogen production	Chemical absorption, PSA
	Hydrogen gasification residues	Pre combustion (gasification) + chemical absorption
	Fluidised catalytic cracking	Post combustion using chemical absorption, or oxyfuel technology
	Process heat	Post combustion using chemical absorption, or oxyfuel technology
Biomass conversion	Synthetic natural gas	Pre combustion (gasification) + chemical absorption
	Ethanol production	Dehydration only
	Hydrogen production from biomass	Pre combustion (gasification) + chemical absorption
	Black liquor processing in pulp and paper manufacturing	Pre combustion (gasification) + chemical absorption

Table 1: capture technologies considered in the roadmap

The most important result of the Roadmap has been a set of actions, produced to help accelerate the deployment of CCS in industry in order to reach the levels required in order to contribute to stabilizing global greenhouse gas emissions to 450ppm by 2050.

4.3. Question and answer session 1

How did you envisage how many CCS plants will need to be deployed?

The modeling results were portrayed in figures (such as Figure 1) which state the amount of CO_2 that could be captured at a given period in time. This potential is based on the expected demand for materials and the associated emissions increases. Figures were

[1] There are a number of existing gas separation techniques such as membrane separation, chemical absorption using solvents including amine-based solutions monoethanolamine (MEA), methyldiethanolamine (MDEA) and hot potassium carbonate based processes, physical sorbent based process, pressure swing absorption (PSA) and cryogenic separation process. Selection of the appropriate process is dependent on a number of factors including end use specification, gas inlet pressure, cost, size, weight and maintenance needs (Zakkour & Cook, 2010).

[2] Understood a most suitable capture technology (Posco, 2008).

obtained for the average emissions per source (type of installation), which we then divide the total amount abated by the average installation size for each sector.

How far does the IEA BLUE map scenario meet the IPCC scenarios?
The BLUE Map uses the starting point from the IEA World Energy Outlook.

Why is the petrochemical sector not included in the Roadmap?
To a certain extent, the petrochemical sector is included in the high-purity sector.

How is the issue of carbon intensity addressed in the IEA's model?
The IEA has information regarding the various energy intensities of the best available technologies (BAT) for blast furnaces and DRI for example. Every time a new plant is built, the model assumes that BAT is deployed.

Regarding CO_2 negative solutions, how is biomass supply addressed?
The model assumes that sufficient biomass is available, but does not distinguish between various sources or types of biomass.

Do you take into account the different climate change scenarios on biomass production in the IEA model?
Unfortunately the information and data on this issue is scarce.

5. Sector focus

As part of the Roadmap, two additional assessments were completed to inform the road mapping activity. The first one, on Enhanced Oil Recovery was undertaken by Michael Godec (Advanced Resources international) providing as input a summary assessment of the potential opportunities and constraints for the application of carbon dioxide enhanced oil recovery (CO_2-EOR), using CO_2 captured from industrial sources. The second one, on source sink matching for industrial installations was completed by Yann Le Gallo (Geogreen). This assessment is intended to give decision-makers and industry stakeholders essential information related to the deployment of industrial CCS.

5.1. Emissions sources and reservoir matching

Sources of CO_2 in the five industrial sectors have been considered, based upon the emissions from the sources listed in the IEA GHG CO_2 database which provides their geographical location. The assessment serves as a basis for identifying the steps that need to be undertaken to deploy industrial CCS from where it is today to 2050 with the objective of achieving global GHG reduction targets.

The analysis, which uses a qualitative source-sink matching approach, focuses on eleven regions throughout the world. The quality of the publicly available data varies greatly and does not usually indicate the potential storage resource. Therefore, a specific methodology was developed in order to estimate the storage resources, and large uncertainties are inherently associated with such a methodology.

A limited number of early opportunities have been identified in each of the eleven regions considered in the study. In most regions, the storage location is a limiting factor as quite often, the available storage is too far from the emissions sources. These restrictions are quite severe for industry sectors considered in the study.

5.2. Enhanced oil recovery

Enhanced oil recovery (EOR) is a term used for a variety of techniques for increasing the amount of crude oil that can be extracted from an oil field. As part of the CO_2-EOR process, CO_2 is injected into an oil-bearing stratum; though CO_2-EOR operations have traditionally focused on optimizing oil production, not the storage of CO_2. Nonetheless, CO_2-EOR can result in effective storage; in general, most of the initially purchased CO_2 for CO_2-EOR operations (not that which is recycled) can be stored at the end of injection.

CO_2-EOR technologies have been profitable in commercial scale applications for over 30 years, primarily in the United States. Natural CO_2 fields are currently the dominant source of CO_2 for the U.S. CO_2-EOR market, providing CO_2 supplies amounting to 47 million metric tons per year. Anthropogenic sources are accounting for steadily increasing share of this CO_2 supply, currently providing 12 million metric tons per year of CO_2 for EOR. However, CO_2 reserves from natural sources have the potential of supporting the production of only a small fraction of the oil resource potential achievable with the application of CO_2-EOR.

Substantial growth in oil production from the application of CO_2-EOR requires significantly expanded access to industrial sources of CO_2. The greatest impact associated with CCS in value-added reservoirs such as CO_2-EOR may be derived from their ability to produce incremental oil, with the revenues resulting from this incremental production serving to offset costs associated with deploying CCS. The deployment of CO_2-EOR, especially in areas where it has not been deployed before, also contributes to the body of knowledge needed to implement CCS.

Since significant expansion of oil production utilizing CO_2-EOR will require volumes of CO_2 that cannot be met by natural sources alone; industrial sources of CO_2 will need to play a critical role. Thus, not only does CCS need CO_2-EOR to help promote economic viability for CCS, but CO_2-EOR needs CCS in order to ensure adequate CO_2 supplies to facilitate growth in the number of and production from new and expanded CO_2-EOR projects.

5.3. Question and answer session 2

When can EOR actually be classed as CCS?
Yes. When CO_2 is captured by CCS, that would have otherwise have been emitted, EOR is then contributing to the abatement potential of CCS technologies.

Will CCS be allowed into the CDM?
CCS is provisionally accepted as an official CDM activity, however certain modalities and procedures need to be fulfilled before the first project methodologies can be submitted to the CDM Executive Board. On the 20-21 June 2010, the **Subsidiary Body for Scientific**

and Technological Advice (SBSTA) will meet in Bonn for a workshop to discuss possible ways to address these issues.

What needs to be implemented for monitoring CO_2 storage from EOR?
More than mass balance will be needed in order to be sure that CO_2 is stored in a manner predicted by geological models. You need to do a range of surveys and site characterization, but the costs are not expected to be large.

I didn't see any information on risk assessment, is this something to consider in the roadmap?
It is extremely important, but risk assessment has been considered in the EIA Technology Roadmap for CCS (2009). This issue is not considered specific for CCS in industry.

There is a large range of storage data, some is not there, other is not publicly available, and some is from literature that has very different assumptions and cannot be used consistently. Which organizations could take care of this situation and ensure that policy makers are given access to the best available information?
This topic was discussed by the group however no conclusions were reached.

6. Breakout groups with specific assignments

The main goal of the first day of the workshop was to request inputs from stakeholders on the draft key messages, actions and milestones outline by the roadmap. The participants were distributed between small groups (4 to 8 people) with specific focal points, based on their respective experience and/or organization. The subjects of the five breakout groups were as follows:

- Needs for capacity development and international cooperation
- Identification of lighthouse projects (early opportunities)
- Business model actions and milestones
- Policy and financial actions and milestones
- EOR actions and milestones

Each group was given a set of key points, based on the main messages contained in the draft roadmap, and asked to discuss and validate the appropriateness of these points. The keys points and a brief record of the discussions that took place during the breakout sessions are provided in the following sub-sections.

6.1. Needs for capacity development and international cooperation

> *Although information is available on the technology, economics and policies relevant to industrial CCS, many gaps and challenges in knowledge and action remain. The most important ones include:*
> - *Lack of emission and emission projection data.*
> - *Lack of real data on engineering costs.*
> - *Inconsistencies in reporting on estimated cost data.*
> - *The confidentiality of industrial data.*
> - *Lack of awareness and political will to deliver industrial CCS.*
> - *Low awareness and limited relevant human capacity in developing countries.*
> - *Lack of progress on developing policies for CCS in a global framework.*

The discussion focused on two main issues (awareness and capacity building) on which the participants had different understanding. Both were discussed and defined in the context of CCS activities

In terms of awareness-raising, the group agreed that different stakeholders required targeted messages. For example, for policy makers it was mentioned that although they are aware of the concept of CCS as a technology and its broad purpose, they generally had low awareness of specific details, and did not yet see CCS as a potential business opportunity. It was proposed that the need for stating the importance of the business case for CCS, through advocacy, had to be made at a high level to policy makers and government officials. The need for financial incentive or government directive to progress CCS was brought up throughout the discussion.

With regards to capacity building, stakeholders could not articulate which activities could be undertaken to promote the uptake of CCS. Not only was their perception of capacity building limited, but it appeared that at this stage, their main concerns were to do with a lack of regulations and financial incentive. Some members of the group had the perception that capacity building would only be workshops and awareness-raising. Even when other types of activities were provided as examples, this did not fuel the discussion. They did mention that technology transfer issues had to be addresses (such as IPR and patent costs) but could not define how capacities could be increase to accelerate this transfer. Another issue coming out of the break out session was the desire for technology capacity building to be targeted and specific. Whilst the type of technology was not identified the desire to be able to learn the complete technology was mentioned, rather than just composite parts.

Part of the discussion was focused on country-specific activities (including Brazil, Mexico and Argentina). However, participants agreed that country specific recommendations should not be made, but rather focus on the broader actions that need to be addressed in all countries. International cooperation was briefly discussed in terms of stakeholder engagement. Several participants mentioned the desire to safeguard data.

The issue of CCS in the context of CDM was also discussed in detail. While it was not the objective of the session, participants felt it would not be a driving mechanism for the technology in developing countries. Some participants proposed that the additionality of the CDM could not be demonstrated financially, since the CER returns from CCs projects would be too small to cover for any of the additional investment costs.

6.2. Identification of lighthouse projects (early opportunities)

Key points to validate:

- *Of the current full-scale CCS projects in operation, most are based on industrial processes. Yet of the 80 projects identified by the IEA's report to the G8 (IEA/CSLF Report to the Muskoka 2010 G8 Summit prepared with the co-operation of the Global CCS Institute - Carbon Capture and Storage) only gas processing is well represented with few projects in the ammonia and iron and steel sectors. This roadmap shows that more low-cost opportunities for lighthouse CCS demonstration projects exist in industry.*
- *In order to gain a deeper understanding of the potential for CCS in industry, data on current emissions and technologies, as well as cost data and projections need to be improved. Large data gaps exist in industry. In addition, greater effort is needed on global source sink assessments to better map CO_2 capture and storage opportunities in industry, including CO_2 storage opportunities in EOR operations.*
- *"Clusters" of industrial capture projects. In these cases several CO_2 sources have been matched with a suitable CO_2 sink or reutilisation opportunity. Suitable storage sites would be considered unattractive if located far away from sources. By clustering of sources and developing single pipeline infrastructures to transport CO_2 over large distances, storage in a single suitable site could become feasible due to reduced costs. The matching of sources and sinks lies at the core of the feasibility of CCS.*

The participants in this breakout generally agreed and understood the importance of the key points proposed by the roadmap team. The breakout group was composed of primarily national representatives from the Brazilian petrochemical and cement industry, and the participants were keen to highlight the relevance of CCS for there respective industries.

In Brazil, a number of companies are following CCS but are not directly investing, as they have a number of ways to reduce CO_2 by other means. Before CCS can be put on the agenda, it seems logical that lower cost options in energy efficiency must be taken. Companies are following the option out of interest, but not to deploy CCS. Currently in the cement industry energy efficiency takes the priority, and also the possibility of using biomass as a substitute for conventional fuel. The replacement of clinker, the energy intensive product of the cement producing process, with slag from the steel industry or other sources such as pozzalina is also important. In Brazil, cement plants are often far away from the coast, so storage areas will be need found inland. The cement plants are often individual plants, and not often in clusters. Limestone is a very abundant material and the plants are often placed far away from cities due to environmental restrictions.
For companies in the Brazilian petrochemical sector a pressing issue is energy efficiency and electricity prices. Some companies have CO_2 intensity and energy efficiency targets but consider that these could be reached by first implementing energy efficient measures and renewable energy technologies, rather than CCS. However, acid gases

capture (CO_2 and H_2S) with amine technology is standard technology in the petrochemical sector. Post-combustion capture is less known.

6.3. Business model actions and milestones

Key points to validate:

- *The most suitable mechanisms for supporting CCS may vary as the technology matures. Due to greater international competition in industrial sectors than in power, carbon leakage may take place when CCS is pursued in industry through pricing mechanisms. Hence, the financing and incentive mechanisms appropriate for industry may need to differ from those suitable for the power sector.*

- *Currently, greater focus is needed to specifically support CCS technology in industry, with justifiable role for subsidies for investing in and operating CCS. Over time, a more technology neutral perspective could become increasingly appropriate with CCS incentivised primarily by its ability to reduce CO_2 emissions.*

The participants generally agreed with the business models actions outlined (see box above). It was identified that business models for CCS may stem from costs saved by avoiding the emissions of greenhouse gases to the atmosphere, providing that some sort of incentive scheme such as the EU ETS is in place. Value could also be generated through the utilization of the captured CO_2 to enhance the recovery of hydrocarbons. Given a demand for CCS technology and expertise, there may also be a business cases for companies which choose to become key equipment and advice providing vendors.

Carbon leakage was identified as a serious issue for industrial sources. It was agreed that industrial sources are mobile, the international nature of a number of industrial subsectors, and the availability of cheap transportation means that ramping up industrial output in carbon havens and transporting to meet demand in regions with carbon penalties is a stark possibility. There are a number of potential solutions to this problem, such as border taxes, but also by introducing the shipping industry into emission reduction schemes will act to deter the long distance transportation of goods by raising the costs.

6.4. Policy and financial actions and milestones

Key points to validate:

- *Governments need to ensure that CCS demonstration programmes include projects in fuel transformation, gas processing, cement, iron and steel and chemicals manufacturing. USD 26-36 billion will be needed by 2020 to fund 19-43 demonstration projects).*
- *The Roadmap envisages that more than USD 250 billion of industrial CCS investment will be required in developing countries from 2020 to 2030. The high cost of CCS is the key barrier to implementation in developing countries. If CCS can be implemented through the Clean Development Mechanism (CDM), this cost barrier could be overcome and spur CCS deployment in developing countries. It is likely that the first CCS-CDM projects will be industry. For developing countries, CCS could be part of a low-carbon industrial development strategy.*

The aim of the group was, first, to validate a number of draft key messages from the roadmap related to investment needs over time and in different regions, and second to discuss the actions and milestones arising from those needs in both finance and policy. The participants noted that the key messages related to investment needs for CCS in industrial sectors were relevant, except that they seemed to address OECD country investments up to 2020, and investments in development countries in 2020-2030. The participants indicated they wished to see numbers in OECD countries beyond 2020 and in developing countries before 2020 too. In addition, although it was acknowledged that the high costs of CCS are a main barrier, other barriers are also important. One key conclusion was that if CCS projects could become operationalized under the CDM modality of activities, CCS investment in developing countries would be encouraged, It was also highlighted by the participants that the first CCS in the CDM projects would likely be in industry, and that given this incentive, CCS could be part of low-carbon industrial development strategies in developing countries.

Regarding the finance and policy actions and milestones, a number of additions were made to the draft text. It was discussed that the role of international and regional development banks is important – in addition to raising awareness with them, an explicit recommendation was included regarding funding of the incremental CCS part of investments as part of multilateral bank strategies. It was noted that CCS in industry would be perceived as not in competition with renewable energy sources. For the policy actions, milestones were added indicating which actions should happen when.

In OECD countries, it was considered relevant immediately to explore sector-based approaches for high-purity sources and potentially the iron and steel sector, including technology transfer provisions. In addition, it was suggested that a mechanism is developed that rewards negative emissions, and that governments provide incentives to accelerate the commercial scale CCS deployment in industry beyond the demonstration phase. For non-OECD countries, the latter action could take place later, but capacity development and awareness raising need to take place right away. For sector-based approaches, non-OECD countries will need support from developed countries and some degree of pooling of international funds could be considered for this purpose.

6.5. EOR Actions and milestones

Key points to validate

- *In order to gain a deeper understanding of the potential for CCS in industry, data on current emissions and technologies, as well as cost data and projections need to be improved. Large data gaps exist in industry. In addition, greater effort is needed on global source sink assessments to better map CO_2 capture and storage opportunities in industry, including CO_2 storage opportunities in EOR operations.*
- *CCS in the high-purity sector represent early opportunities for CO_2 storage demonstration as these processes yield high-purity CO_2 and only compression, transport and storage is needed for CCS. If these opportunities can be linked to EOR operations, costs can be lower than USD 10/t CO_2 or even negative.*

With regard to the uncertainties preventing EOR deployment, the general conclusions of the breakout session was that a number of uncertainties exist related to both economic and technical issues, and that the roadmap should focus on strategies and actions designed to shed some light on these uncertainties.

The types of policies needed to pave the way for technology development to effectively take advantage of early opportunities for CCS with EOR, the primary policy would be government incentives that help offset the high costs of deployment. The primary policy instrument identified was giving some value to CO_2 emissions stored. In Brazil, a carbon tax on CO_2 emissions will have collateral effects and hurt agricultural sectors. It was felt that especially in the case of Brazil; there was a weak economic driver for CO_2-EOR that currently limits the relative economic attractiveness of EOR opportunities. In fact, even where CO_2-EOR opportunities appear to be economically viable, there are other possible options that could be pursued that are believed to be more profitable, so the EOR opportunities are relative low on the list of investment priorities. The session participants felt that overcoming this would require a common global commitment from governments, in order to create a "level playing field."

7. *Focus on Brazil and Latin America*

7.1. Petrobras initiatives on CCS

Petrobras recognises CCS as an important climate change mitigation technology. At present, CENPES (Petrobras R&D center) has two programs focusing on the capture and utilisation of CO_2; PROCLIMA, a technological program on climate change initiated in 2007; and PRO-CO2, a technological program focusing on the use of CO2 to enhance oil recovery in pre-salt oil reservoirs. Petrobras is also involved in CCS R&D projects including the CO_2 Capture Project (CCP); CO2PIPETRANS & CO2QUALSTORE. Petrobras expects to invest approximately US$ 200 million on CCS between 2010 and 2015.

Petrobras have been injecting CO_2 into the Buracica field in the Reconcavo basin for 22 years for the purpose of EOR. The company is also actively developing techniques for monitoring, measure and verification of the stored CO_2, as well as exploring rock/fluid interactions, well integrity and geochemical monitoring. Petrobras has recently discovered large deposits of oil in pre-salt reservoirs, and such hydrocarbon deposits have large amounts of CO_2 in the producer gas. The company is considering capturing this CO_2 and utilizing it for either EOR locally or in other fields, however this CO_2 could also be stored in depleted gas fields or saline aquifers.

7.2. An introduction to the activities of CEPAC

CEPAC is the Carbon Storage Research Centre in Brazil. The Centre is a joint venture between the Pontifical Catholic University of Rio Grande do Sol (PUCRS) and Petrobras. The role of the Centre is to conduct research on the storage of CO_2, operate and support CCS pilot projections and develop site selection and screening criteria. The organisation involves a diverse team of 40 experts including professors, researchers, graduate and undergraduate students. At the 1100m^2 Centre in Porto Alegre, a range of laboratories are equipped to undertake studies on supercritical CO_2, coal characterisation, reservoir characterisation, well-bore integrity and numerical modelling. One of the main projects that the Centre is working on, CARBMAP, aims to develop and manage a GIS database which includes possible storage locations, sources and existing infrastructure locations. The final product will be able to facilitate the planning of future CCS installations and infrastructure in Brazil.

7.3. The position of the Brazilian government on CCS

Brazil meets the majority (approx. 80%) of its electricity demand through the use of hydropower, which means that the emissions from energy generation are relatively low. The majority of Brazil's emissions are generated through land-use change, mainly due to the deforestation of the Amazon rainforest. Because of this, it seems more important for Brazil to first try to reduce its emissions from land-use change using other potential UNFCCC mechanisms such as REDD (Reducing Emissions from Deforestation and Forest Degradation. Nevertheless, given the emissions profile, CCS could be much more relevant for the industrial sector for reducing CO_2 emissions. How the public perceive CCS may also act as a barrier to the deployment of the technology, and many questions remain regarding the safe geological storage of CO_2.

7.4. The Petrobras Oxyfuel Fluid Catalytic Cracker

A fluid catalytic cracker (FCC) is an important process in the refinery and petrochemical sectors, which is used to breakdown heavier hydrocarbon compounds into lighter more volatile forms. Petrobras has been conducting the possibility of capture CO_2 from fluid catalytic crackers since 2005. As part of the third phase of the CO_2 Capture Project, Petrobras has decided to test oxyfuel-combustion technology at its FCC large scale pilot plant, with the first results expected in late 2011. The use of oxy-combustion instead of post-combustion capture is expected to reduce the cost per tonne of CO_2 avoided by 60%. The oxy-fuel FCC is understood to result in a flue gas with a CO_2 content of 85%.

7.5. Renewable CCS from sugar fermentation (The RCCS Project)

The RCCS project in Sao Paulo state, aims to promote the combination of CCS with a bio-ethanol production process, based on sugar fermentation. Biomass processing with CCS is very interesting given that it can actually achieve net negative emissions from the atmosphere. The RCCS project was designed based in the vast Brazilian experience in sugar, ethanol and biogas-to-electricity production in the sugarcane mills. The proposed project is globally significant because over 80 countries grow sugarcane, and Brazil is viewed internationally as a leader in technological innovation and competitiveness in the sugarcane processing industries.

8. Specific barriers to CCS in industry in Brazil and Latin America

Panel of speakers: Leonardo Beltran, Maria Christina, José Domingos Gonzalez Miguez

What are the main barriers which are deterrent to CCS in Latin American countries?

Mexico has established a taskforce to explore the potential of CCS. The working group includes the Ministry of Environment and Economy, and the Ministry of Resources, and there is also input from industry and from academic institutions. The objective of this group is to develop a national roadmap. This work group has just produced a paper on the status of CCS in Mexico and will now focus on understanding the barriers to CCS in Mexico.

The government is considering creating a legal framework that is conducive for CCS in Mexico, as at present it is unclear who would be responsible for the CO_2 once stored. Regulations are also needed for the capture and the transport of CO_2, and the use of CO_2 for EOR. Infrastructure is a big challenge for Mexico, if the sources do not match with the sinks, transport pipelines will need to be built, and this raises the question about how to merge CCS installations with the current infrastructure. The project needs to be a bankable project. If the project is not feasible from an economic perspective, it will not be accepted by the government and the public. If CCS may be proven profitable, other challenges can be overcome. The barriers that Mexico faces may be similar to other countries in Latin America, and perhaps in the rest of the world.

Brazil faces the same problems as Mexico, but there are additional barriers. For example the technological maturity of capture technologies for large point sources is not yet available, and at an early stage of development. In regard to reservoirs, careful site selection is needed. Long-term liability is an issue, and geological risk such as earthquakes, could cause storage problems. The public may perceive such an event happening, leading to a release of CO_2. Furthermore, industrial standards are needed before CCS can be implemented on a broad scale.

From an Argentinean perspective, the main barrier is knowledge of storage and how CCS can be integrated with current technologies. Also, there are concern on the risks in regarding to safety and environmental issues. Still, Argentina supports CCS in the context of the CDM as a technology promotion mechanism.

The panel discussed the issue of people living close to a possible storage area are normally concerned. The risks and perceptions associated to the nuclear power industry and CCS were compared briefly.

9. The Latin American Applicability of the Roadmap

What is the relevant for Latin American countries in the roadmap? What would you really like to see in the roadmap?

Panel of speakers: Francisco Almendra, Roberto Lacy, Jose Roberto Moreira.

CCS requires multidisciplinary expertise, so to undertake this type of efforts requires knowledge of several disciplines. A document like a roadmap, that concentrates information, facilitates identifying the key issues and right sources. Furthermore, a high-level roadmap produced by a number of globally well respective institutions adds creditability for projects seeking funding in Latin America.

The roadmap support previous efforts in CCS, including the IPCC report from 2005, yet it should comprise the results from the latest literature. Also, it should highlight the fact that even though CCS is an expensive technology, it can be applied under certain circumstances. It is important to have a roadmap available that can support advocating a technology at country-level.

Who would use it? Who would it be helpful for and how best to disseminate the document?

There are a number of people that would benefit from using such a roadmap, primarily:

- Energy ministers
- CEOs of energy companies and industry
- Business organizations from oil and gas and industrial sectors
- Academic organizations
- Potential project developers
- general public

The roadmap should show new opportunities to project developers that may have been overlooked, for example CCS in the bio-ethanol industry. It can also help to stimulate conversation on CCS by industry organizations. Workshops and dissemination is important.

10. Close and next steps

The results from the discussions and breakout groups will be worked into the final draft of the roadmap. The roadmap will be drafted by UNIDO and the IEA and reviewed by experts over the summer of 2011. The launch of the roadmap is currently planned to take place in Beijing during the Ministerial Meeting of the Carbon Sequestration Leadership Forum (CSLF) in September 2011.

Annexes

Annex 1: Annotated agenda

Annex 2: Participants list

Annex 3: Presentations

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