Meeting Notes
CCS Roadmap Meeting: Technology Focus
IEA Secretariat, Paris, France
6-7 November 2008

Background

In 2007-08, the International Energy Agency (IEA) collaborated with the Carbon Sequestration Leadership Forum (CSLF) to produce a series of high-level recommendations for the G8 leaders on CCS. This was followed by IEA's *Energy Technology Perspectives* 2008 report, which included preliminary CCS roadmaps with steps that need to be taken in the near- medium- and long-term if CCS is to make a meaningful contribution to global Greenhouse Gas (GHG) reduction efforts by 2050. In July 2008, the G8 leaders at their Japan summit asked the IEA to continue to work with the CSLF to advance deployment and demonstration of CCS worldwide. They asked the IEA to develop a CCS Roadmap to achieve broader international consensus on the key technology, policy/regulation, financing and public acceptance milestones that must be achieved if CCS is to make a meaningful contribution to climate change mitigation efforts.

The IEA started this CCS Roadmap process with a meeting in November 2008 which focused on technology. This document summarises and organises the input received at that meeting. Notes taken at the meeting and the summary presentations were the primary sources for this document. This document is not a comprehensive discussion of all of the issues; rather, it is a documentation of the discussion that took place. This information will be supplied to participants in the second CCS Roadmap meeting taking place on 2-3 February 2009, which will focus on policy/regulation, financing and public acceptance. It will also provide important input into the final CCS Roadmap document, to be published in June 2008.

If you have any questions about the IEA CCS Roadmap, please contact Tom Kerr at tel. +33 (0) 1 40 57 67 84; email tom.kerr@iea.org. Also, the IEA website now has more detailed information on CCS, visit http://www.iea.org/Textbase/subjectqueries/cdcs.asp for more information.

<u>Opening Presentations</u>

Nobuo Tanaka, Executive Director, IEA. IEA's *Energy Technology Perspectives* indicates that existing energy policies will see CO2 emissions increase by 130% between now and 2050, mainly the result of higher levels of fossil fuel consumption. An energy technology revolution is needed to address this unsustainable pattern. In particular, we must increase energy efficiency, decarbonise the power sector and revolutionise transportation. CO2 capture and storage (CCS) is one of the most vital options for revolutionising power generation and industry, with CCS projected to deliver 20% of the total CO2 savings needed to cut global emissions by 50% by 2050. In particular, CCS holds great potential for coal- and gas-fired power plants, as well as for some activities in the industrial sector, such as cement, steel and chemical production.

During the last G8 Summit, in Hokkaido in July 2008, G8 Leaders called for 20 CCS demonstration projects to be committed by 2010, as a first step toward broader deployment. Given the lead time involved in plant construction and site assessment, this means that these plants will not be operational until between 2015 and 2020. While these plants will be expensive, we must bear in mind that without CCS, emissions abatement to the levels required would be up to 70% more costly. In order to accelerate deployment for CCS, the G8 has asked the IEA to enhance international collaboration. Thank you to the IEA Working Party on Fossil Fuels, the IEA Greenhouse Gas R&D programme, the IEA Clean Coal Centre, and the Carbon Sequestration Leadership Forum (CSLF), who have all been leading separate international efforts on CCS. Together, we will address the CCS challenge. Good luck with this Roadmap meeting, an important first step.

Jostein Dahl Karlsen, Norway Ministry of Petroleum and Energy, Chair, IEA Working Party on Fossil Fuels. IEA is well-placed to champion collaboration, using its convening power, analytical prowess and outreach to non-member countries. The G8 early opportunities workshops' high-level G8 recommendations were a foundation for the 2008 G8 meeting announcements on CCS. The Carbon Sequestration Leadership Forum and the IEA Working Party on Fossil Fuels are key Allies to the IEA, and we look forward to working with the IEA on this Roadmap. The Key Challenges to CCS Deployment are:

1. Cost (financing early investment, cost reduction)
2. Urgency (technology lock – in)
3. Scaling up (based on the goals in the *Energy Technology Perspectives*)
4. Achieving collective action

For the CCS Roadmap, the following priorities should be addressed:

1. Assessing how current G8 commitments will impact CCS implementation
2. Identifying how to achieve technology pathways (cost reductions a key focus)
3. The role of early opportunities
4. Scaling up

Kamel Bennaceur, IEA, then presented a summary overview of CCS analysis and global status, pulling from the recent IEA publication *CO_2 Capture and Storage: A Key Carbon Abatement Option*. Key points included:

- CCS is part of a lowest-cost GHG solution
- In the IEA BLUE scenario, CCS has a potential of nearly 10 Gtonnes stored per annum, with 55 % in the power sector, while in the ACT scenario, the potential is larger than 5 Gt/year
- CCS needs to expand rapidly outside of OECD countries after 2020
- CO2 Capture is 2/3 of the total cost of CCS
- For CO2 storage, saline aquifers are the most likely long-term solution
- For CCS demonstrations, there is a need to coordinate
- Issues include financing/funding, legal aspects, public acceptance, cross-border technology transfer and including CCS under GHG instruments, including CDM

Tom Kerr, IEA, and **Colin Henderson, IEA Clean Coal Centre,** discussed the role of technology roadmaps, including the *Energy Technology Perspectives* series and the recent Chapter 7 in the IEA book *CO_2 Capture and Storage: A Key Carbon Abatement Option*. These materials were given to participants as background information for the meeting. The specific goals for the meeting are to facilitate greater international collaboration/coordination on CCS, to accelerate the Research, Development and Deployment (RD&D) process, to track progress toward the 20 G8 projects and to reduce costs and improve efficiencies. This effort will not develop a detailed Roadmap from the bottom-up; instead, this effort will build from existing national and international efforts (including the Clean Coal Centre's clean coal roadmap and the CSLF's roadmap). We will make every effort to coordinate these Roadmaps at an international level to ensure consistent messages.

Source Documents: Dahl Karlsen, Bennaceur, Kerr presentations; IEA synthesis of country roadmaps; IEA book *CO_2 Capture and Storage: A Key Carbon Abatement Option;* IEA book *Energy Technology Perspectives 2008*; IEA/CSLF Early Opportunities Workshops Recommendations; CSLF CCS Roadmap (2004).

Breakout Group Results: CO2 Capture

The Capture group was chaired by Rachel Crisp of the UK's Department of Energy and Climate Change. The group defined CO2 capture to include pre-combustion, post-combustion and oxy-fuel technologies, and to apply to coal-fired and natural gas-fired power generation. Industrial issues were less of a focus for this group because there was a lack of expertise in the group. However, other IEA Roadmaps (including the Cement Roadmap) will look at CCS industrial sectors to understand their differences in cost, maturity of components, and integration with CO2 transport, among other issues. The IEA will integrate these efforts in the final Roadmap document.

Technology Baseline

The group identified several additional sources of information that should be included to document the current status of CO2 capture technology development and demonstration, including:

- The EU Zero Emissions Platform Work Group Reports[1]
- The Coal Utilization Research council and EPRI Clean Coal Vision
- The US DOE National Energy Technologies Laboratory (NETL) Baseline study,[2] which identified costs of various CO2 capture and storage components
- Canada's CCS Technology Roadmap, developed in 2006, which was updated in January 2008 by the Canada-Alberta CCS Task Force with further CCS recommendations[3]
- The McKinsey & Company EU CCS Report[4]
- CO2 capture projects in Norway (CLIMIT), France, Germany (COORETEC and Geotechnologien programme) and the Netherlands (the CATO2 programme[5] and the Rotterdam Climate Initiative)
- The IEA GHG Programme's list of existing and planned CCS demonstration projects
- The World Resources Institute's Guidelines for capture (demonstrate all approaches, evaluate environmental impacts, etc.)
- Other industrial sector CCS efforts (e.g., cement, steel, refineries, fertilizer)[6]

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[1] See www.zero-emissionplatform.eu/website/docs/ETP%20ZEP/ZEP%20Technology%20Matrix.pdf

[2] See www.netl.doe.gov/energy-analyses/pubs/Bituminous%20Baseline_Final%20Report.pdf.

[3] The Government of Canada committed CAN$250 million of its 2008 budget for CCS research, with CAN$140 million on industry-led projects for advancing CCS technologies. The province of Alberta also announced a CAN$2 billion fund for CCS, which will be managed by the Alberta CCS Development Council.

[4] See www.mckinsey.com/clientservice/ccsi/pdf/CCS_Assessing_the_Economics.pdf

[5] See www.eon-benelux.com/eonwww/publishing.nsf/Content/20080701+Afvangproject+CATO-2_English

[6] E.g., the World Business Council on Sustainable Development's Cement Sustainability Initiative

The following gaps were identified:

- Lack of transparent, regionally applicable, peer reviewed economic data on CO2 capture
- Longer-term research needs: the current focus on large-scale demonstration should be complemented by support for longer-term CCS research and development needs. We need to look beyond the first round of demonstrations and plan a future expansion of CCS that captures the RD&D needs for each phase.
- Need to consider the CCS human resource needs (e.g., education and training of skilled workers)
- Need to engage key emerging economies like China, India, S. Africa and others
- Intellectual property issues related to CO2 capture need to be addressed (affects technology transfer to emerging economies)

There was not much of a concern about CO_2 capture RD&D project overlap, as this is typical for technology development.

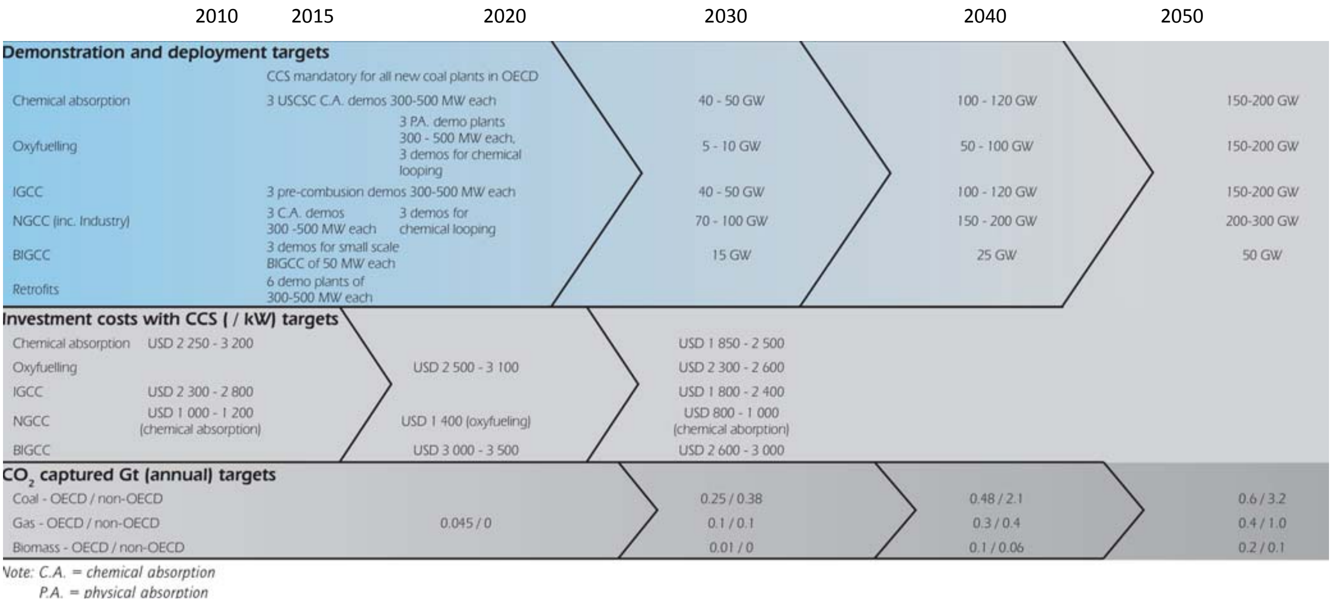
Breakthrough Technologies/Approaches

The group identified the following potential breakthrough technologies/approaches, and recommended that they be included in the roadmap:

- Chemical looping (if it is shown to have lower energy consumption)
- Membrane breakthroughs can reduce size and cost
- Materials breakthroughs might have a big impact
- Cryogenic separation which eliminates the use of solvents
- Other power generation cycles (e.g., oxyfuel with high-purity O_2 combustion and minimum or zero flue gas recycle), and new turbine integrated technologies based on helium or supercritical CO2 as the working fluid.
- Direct carbon fuel cells

Technology Metrics/Milestones

There were concerns about the CO2 capture metrics contained in *CO2 Capture and Storage: A Key Carbon Abatement Option* (reproduced below).



There is a need to produce validated data to steer policy. A smaller working group will be formed to develop and share CO2 capture metrics.

Breakout Group Results: CO2 Transport and Storage

Technology Baseline

The group was chaired by Per Gunnar Stavland of StatoilHydro. The group felt that there are existing studies that should be included in the Roadmap process, including the EU Zero Emissions Platform Work Group Reports; further, an IEA GHG project looking at the technology learning from large-scale projects will produce results in early 2009 that can be fed into the Roadmap. There is a need to summarize major CCS RD&D activities in one place, and to keep information transparent and publicly available.

Ship transport is an early option for CO2 transport that merits further exploration. NEDO in Japan has a project on CO2 tanker transport; the project will study the liquefaction of CO2 as well as CO2 hydrides. Norway and other Nordic countries are implementing CO2 transport via ships with liquefied and refrigerated CO2 and stacking pressured vessels of compressed CO2. A recent paper presented at GHGT9 summarises the options for ship transport.

Business models for CO_2 pipeline transport expansion are needed. There is currently an EU tender on how to link sources to sinks, possibly modeled after the trans-European pipeline network. There is a need to distinguish between the infrastructure that is needed for the demonstration period up until 2020 and for long-term commercialization. There are also country-specific studies, using sources, sinks, existing pipelines and tools (such as ARCGIS) to determine the least-cost option for infrastructure development. An example is the recent Dutch study presented at IEA GHG's GHGT9; other examples are Australia's Geodisc and Natcarb in the United States.

To develop business models, one way to start is through developing pipeline expansion models, looking at CO_2 transport 'hubs' (as in the recent EU CCS McKinsey study), and weighing the pros and cons of different approaches (including the creation of regional networks/clusters). There is also a need to analyse the expansion over time of CO_2 pipelines by starting with early large-scale demonstration projects (with a priority on EOR/EGR); then expand networks. There is a US storage study from 2003 in the US that examines the potential for early EOR/EGR CCS among 10 basins that focuses on identifying technically and economically recoverable oil resources from state-of-the-art CO_2-EOR technology and is attempting to expand understanding of oil resources in residual zones. This could be a good start.

Business models for CO_2 transport need to clarify the roles that the government could play in funding and regulation of the pipeline infrastructure. Although some sources/sinks will determine pipeline scenarios themselves, more coordinated regional planning offers cost reduction benefits. Pipeline diameters could also be designed to maximize efficiencies, but this needs to be balanced against incentivising too large a pipeline. A cost-reduction aspect that could be considered is the opportunities to site CO_2 transport pipelines next to existing pipelines.

CO_2 stream composition will be an issue for integrated networks; there might be benefits to conducting CO_2 pipeline transport demonstrations to test different co-constituents. The recent World Resources Institute (WRI) guidelines may be useful here.

Safety criteria for CO_2 transport and storage are needed. These standards need to be integrated throughout the capture/transport/storage chain. There is a need for national authorities with monitoring and verification (M&V) data to share information internationally. The North Sea Basin

Task Force[7] brings together Government and industry representatives from the UK, Norway, Netherlands and Germany to address issues related to the transport and storage of CO2 under the North Sea. This could be an example for international collaboration on CCS.

The role of enhanced oil recovery/enhanced gas recovery (EOR/EGR) in early development: could also spur CCS infrastructure funding; this option needs to be further analysed. It is currently difficult to access geologic data for EOR/EGR, as it is typically held by private oil & gas operators. Policy decisions might help free up this data for use by others.

Storage capacity estimation methodologies are needed and much work needs to be done, particularly for saline formation. This is an important gap that should be addressed as a priority. Storage capacity estimation methodologies need to be spelled out in more detail, explaining the different tools and models that can be used. The CSLF has produced two documents on storage capacity estimates, including a proposal for CO2 storage capacity assessment[8] and a comparison between storage estimation methodologies.[9] These documents provide a basis for future work. The IEA GHG is also developing a new project on storage capacity coefficients. The US DOE recently published a new North American Storage Atlas for 2008. In particular, there is a major gap in knowledge on deep saline formations (DSFs), and many DSFs cross international boundaries, necessitating international collaboration. The IEA GHG is completing a study on this, with CO2CRC in Australia. There is a need to understand how well CO2 storage has been assessed globally to identify gaps.

More detailed CO2 storage risk assessment procedures are needed, and should be shared internationally. While national work is underway, stronger coordination between national groups is needed to avoid duplication; there may be a need to move toward a common international approach. A starting point is the CSLF guidelines for CO2 storage risk assessment, which will develop a Phase I Report that:[10]

- Conducts a review of the existing literature on risk assessment for geologic storage of CO2
- Summarizes ongoing risk-assessment activities in various countries
- Highlights critical issues

[7] See http://www.nsbtf.org/.
[8] See www.cslforum.org/documents/PhaseIIReportStorageCapacityMeasurementTaskForce.pdf.
[9] See www.cslforum.org/documents/PhaseIIIReportStorageCapacityEstimationTaskForce0408.pdf.
[10] More information can be found at www.cslforum.org/documents/MeetingSummaryRATFMeetingCapeTown2008.pdf.

• Identifies areas where additional information is needed

The WRI Guidelines also included a set of recommendations for risk assessment, developed via a stakeholder process. These approaches should be looked at together and integrated.

Breakthrough Technologies/Approaches

The following potential breakthrough technologies/approaches were identified as solutions that should be highlighted in the Roadmap:

- Identify integrated CO2 storage assessment approaches that allow for faster, more accurate consolidation of assessment from seismic to full simulation in a user-friendly way. This will help to reduce the time spent on site characterization and simulation, while still allowing for the collection of critical site-specific data.
- Develop pipelines with cheaper composites that are as safe as steel.
- Identify lower-cost solutions for CO2 storage that use simpler platforms/drilling systems. There may be the potential for collaboration between oil & gas and CO2 storage rigs, with the aim of identifying lower-cost drilling options.[11]
- Identify technologies that maximize CO2 confinement by injecting co-products (surfactants) with CO2, producing a foam if leakage occurs to block the leakage.
- Storage in novel formation types (Perodite, basalts, etc).

Technology Metrics/Milestones

The group reviewed the metrics contained in the IEA's *CO2 Capture and Storage: A Key Carbon Abatement Option* (reproduced below).

	2010	2020	2030	2040
Pipeline network				
size of network - km	5 000 - 7 000	15 000 - 25 000	32 000 - 50 000	60 000 - 90 000
investment costs - USD bn	3 to 4.2	9 to 15	24 to 36	45 to 75
Storage				
	Consistent assessment of storage potentials globally			
EOR Gt stored	10 - 1 Mt projects committed	5 - 10 Gt		
Gt stored			50 Gt, 50% DSF 50% EOR + DOGF	250 Gt, 75% DSF

Transport metrics. Setting distance-based metrics (e.g., # kilometers of CO2 pipeline) is not appropriate because the goal is to minimize the cost and length of pipeline. However, there may be a maximum transport distance that could be used as a metric (i.e., a point where it becomes more

[11] Companies in the Netherlands are considering adapting composite tubing and casings that are currently being used for geothermal well drilling for CO2 storage wells. The footprint of these rigs is smaller, storage place for the tubing is smaller and the drilling produces less noise. The system can also be transported via truck.

efficient to transport electricity compared to CO2. Transport cost metrics could be developed by starting with the expected volume based on CO2 emissions levels, taking into account capture, transport and storage volumes. Then a cost target could be developed by breaking down transport needs by cost/km for construction, siting, and O&M, also identifying differences between offshore vs. onshore pipeline costs.

There is a specific need for CO2 pipeline health and safety metrics. While many stakeholders feel that CO2 transport is similar to natural gas transport, regulators need to identify the differences. As a start, it was felt that CO2 transport may need additional arrestors/cutoffs and/or pressure monitors more frequently along pipelines. Also, dehydration of fluids is more important in CO2 pipelines. The types and volumes of impurities in the CO2 stream and the influence on phase behaviour need to be investigated. There is a need to conduct tests to understand the behavior of CO2 mixed with other constituents.[12] There may also be a need to develop different standards for areas with high population density or ecologically sensitive areas. Some countries are undertaking CO2 dispersion modelling; there may be an opportunity to share information internationally.

Storage metrics. There is a need to explain how the IEA CCS Book CO2 storage goals (see figure above) will be achieved by building from the bottom up to better characterize the number (and size) of storage sites which are necessary. CO2 storage metrics also need to address quality along with quantity; criteria need to be developed to ensure storage integrity and identify mitigation plans as a part of a comprehensive risk assessment (rather than projecting "allowable" leakage rates that will hopefully not be achieved). There are petroleum ratings for prospective oil fields; one idea would be to develop ratings for CO2 storage sites and then rank basins at a country level.

There is a need to develop storage cost performance metrics, spelling out the various elements in the process, including injection costs, well drilling, costs for long-term liability coverage, and M&V, among others. The main capital expense will be drilling wells, so the number of wells drilled is a good metric; the Roadmap could develop a performance metric of the number of wells/# tonnes of CO2 injected. Wells are also the most likely source for leakage; the Roadmap should therefore emphasize the minimisation of the number of wells. These sorts of metrics should be shared with rig developers to ensure adequate supply at reasonable cost, as it becoming more difficult to find rigs globally. A group will be formed to develop improved storage metrics.

[12] The WRI guidelines have a helpful table that specify these co-constituents that may be useful here.

Expanding and harmonizing CO2 storage monitoring and verification (M&V) standards. The 2006 IPCC Inventory Guidelines contain recommendations to Annex I countries on how to report on CO2 emissions, and include a methodology for CCS. They are not yet approved, but provide a good start for developing M&V approaches for CO2 storage. These methods have been reflected in the EU CCS Directive, OSPAR and the London Protocol. However, all of these frameworks to date stop short of specifying quantitative performance standards; there is a need to identify performance standards that are in use or proposed by different schemes, and to share these models internationally in an effort to ensure consistency.

<u>**Next Steps – Priority Activities to Be Included in the Roadmap**</u>

Track global progress toward the G8 goal of 20 announced demonstration projects by 2010 and enhance knowledge-sharing among early projects. Three is a need to improve public information about the international progress toward the goal of implementing 20 large-scale demonstration projects. To do this, criteria need to be established, and a publicly accessible list should be developed to track those projects which meet the criteria. The Roadmap could include these criteria and a preliminary list for review and approval by public and private stakeholders. Further, as CCS demonstration expands, there is a need to expand public-private partnerships that combine both research and development and to share this information widely. The new Australian CCS Institute will play a key role here, together with the IEA GHG and the European Commission's Flagship Programme.

Communicate the urgency of CCS to policy makers. The roadmap should communicate how much CCS will need to contribute to combating climate change. It should start with climate targets and explain CCS technology's ability to meet climate targets over time. There is a need to improve the discussion of CCS within the framework of a larger global climate change agreement; i.e., to better explain how CCS can be used alongside other mitigation options like renewables and energy efficiency. The goal is for policy makers to understand the importance of CCS and then to communicate to their audiences about the necessity of CCS.

Communicate the readiness of CCS technology if suitable financing is available. To address concerns that CCS is not yet technically viable, there is a need to develop a detailed characterization of CCS expansion, with timelines and goals for each phase of the CCS deployment process (e.g., early opportunities, demonstrations, pre-commercial, commercial). These phases should then be looked at by policy makers to spell out the different policy support (and financing) that will be needed during each phase.

Communicate action items for policy makers. Policy makers at all levels need more information on specific actions that they can take to make CCS happen by 2030, 2050. There is a need to clarify the time frame for CCS regulatory development, and to engage regulators to provide information on: the specific public health and safety tests that are required and the timelines for regulatory development. There is also a need to identify ways that demonstration projects can move forward in parallel with regulatory development (via an ‘adaptive regulation approach), and to examine ways that CCS demonstration can be “fast tracked” or supported by other innovative regulatory approaches.

Begin to move toward international regulatory harmonization. As several national and international efforts are developing CCS standards and regulations, there is a need to work toward a common approach. This could be started by identifying existing guidelines that have been developed for site selection, M&V, and risk assessment, and then recommending analysis that can take these efforts to the next level. Organisations like the International Organisation for Standarisation (ISO), the IPCC, WRI, and others may be an ally.

Further assess liability and insurance issues. To address uncertainty on the costs and structure for liability for CCS, there is a need to compare different insurance/regulatory options and report on how CCS demonstration projects might be impacted by different proposals, comparing and contrasting approaches. There have been some recent proposals that can start this analysis.

Engaging developing countries is a key priority for CCS. There is a need to ensure that India and China (and other major emerging economies) are fully engaged in Roadmap process. To address this, CCS technology transfer and capacity building efforts could be established to identify targeted countries, and their specific needs to foster projects (e.g., CO2 storage site assessment, risk assessment, or technology demonstration). The cost of CCS project development in emerging economies could be spelled out and potential funders can be approached with this financial information to enlist support (the World Bank’s Partnership Carbon Facility and the Global Environment Facility are two possibilities; there are other potential sources that should also engaged, including the European Investment Bank’s risk sharing facility for CCS projects). There is also a need to explore the role of CCS in the Kyoto Protocol's Clean Development Mechanism. As the CDM will be reformed at the end of 2009, pathways for CCS could be identified to address the technical and political concerns that CCS has raised in the current CDM structure.

Educating the Public and Addressing their Concerns. There is a need for improved public acceptance, including engagement of a wider audience of stakeholders. There needs to be more discussion about how CCS fits into a long-term vision for energy and economic sustainability. Ideas here include fast-tracking biomass CCS demonstrations to evaluate the GHG benefits of this approach; and better explaining the role of CCS as a strategy that works alongside renewable energy and energy efficiency to address climate change. Other next steps include identifying CCS public awareness professionals from around the world and establishing a network for these experts to expand communication around strategies and issues.