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Progress reports

Report on the in-session workshop of the Subsidiary Body for Scientific and Technological Advice, at its twenty-fourth session, on carbon dioxide capture and storage

Note by the Chair of the Subsidiary Body for Scientific and Technological Advice

Summary

An in-session workshop was held at Bonn, Germany, on 20 May 2006 on carbon dioxide capture and storage. Participants exchanged views and experiences on a range of activities relating to carbon dioxide capture and storage, including experiences from demonstration and pilot projects, relevant provisions of the *2006 IPCC Guidelines for National Greenhouse Gas Inventories*, capacity-building for development of this technology and other related issues. Participants identified potential areas where further work was needed to advance carbon dioxide capture and storage.

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I. Introduction

A. Mandate

1. The Subsidiary Body for Scientific and Technological Advice (SBSTA), at its twenty-third session, requested the secretariat to organize, under the guidance of the Chair of the SBSTA, an in-session workshop on carbon dioxide capture and storage (CCS) at the twenty-fourth session of the SBSTA to increase understanding of CCS through an overview of the Intergovernmental Panel on Climate Change (IPCC) Special Report on Carbon Dioxide Capture and Storage and through experiences and lessons learned.

2. The SBSTA, at the same session, requested its Chair to prepare a report of the above-mentioned workshop for consideration by the SBSTA at its twenty-fifth session, to be held in Nairobi in November 2006, and requested that the report and workshop presentations be posted on the secretariat website (FCCC/SBSTA/2005/10, para. 112).

B. Scope of the note

3. This report contains a summary of the 20 presentations made during the workshop by country representatives and experts representing intergovernmental organizations (IGOs), non-governmental organizations (NGOs) and business and industry, and of the general discussions. Ideas on possible further activities on CCS suggested during the workshop could serve as input to further consideration of this matter by the SBSTA at its twenty-fifth session.

C. Possible action by the Subsidiary Body for Scientific and Technological Advice

4. The SBSTA may wish to take note of the information contained in this document and, where necessary, provide further guidance to Parties on possible next steps for advancing the work on CCS technologies, taking into consideration the ongoing work by relevant IGOs and the private sector.

II. Workshop proceedings

5. The workshop was convened on 20 May 2006, during the twenty-fourth session of the SBSTA.[1] It was attended by some 300 participants, including Parties and representatives of business and industry, environmental NGOs and international and regional organizations.[2]

6. The expected outcomes of the workshop were:

(a) A broader understanding of CCS among key stakeholders, Parties, IGOs and the private sectors of CCS through an overview of the IPCC special report and through experiences and lessons learned;

(b) Options for practical steps to be taken by Parties and relevant stakeholders to further advance CCS.

7. In his opening remarks, Mr. Kishan Kumarsingh, Chair of the SBSTA, said that CCS was an emerging technological option with a very high mitigation potential, which could become a key component of a portfolio of complementary strategies and technology options that had the potential to

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[1] A workshop on carbon dioxide capture and storage as clean development mechanism project activities was held on 22 May 2006 in Bonn, Germany and its report is contained in document FCCC/KP/CMP/2006/3.

[2] The agenda of the workshop and all presentations are available at <http://unfccc.int/meetings/sb24/in-session/items/3623.php>.

build a bridge to a low carbon future; he noted the keen interest of Parties in this matter. Mr. Kumarsingh drew attention to the IPCC special report on CCS that describes the potential of this technology to address greenhouse gas (GHG) emissions. He highlighted the importance of CCS in the context of Parties' discussions on further steps to address climate change in the Dialogue on long-term cooperative action to address climate change by enhancing implementation of the Convention and of the Ad Hoc Working Group on Further Commitments for Annex I Parties under the Kyoto Protocol.

III. Summary of presentations and discussions

A. Introduction and overview of carbon dioxide capture and storage technology

8. Mr. Bert Metz, IPCC, said that one of the main findings of the IPCC special report was that CCS was part of a portfolio of options that could reduce the overall mitigation costs and increase flexibility in achieving GHG emission reductions. He noted that the components of CCS systems were at different levels of maturity, ranging from mature market (enhanced oil recovery – EOR) to demonstration (enhanced coal bed methane – ECBM) and research phase (ocean storage). He stressed that a good global correlation existed between carbon dioxide (CO_2) capture and storage sites. With regard to the costs of CCS, Mr. Metz said that an additional 1–5 cents/kWh would be needed, which was equivalent to 20–270 USD/tCO_2 avoided. The predominant costs were for CO_2 capture, but a 20–30 per cent cost reduction in CO_2 capture was expected to take place in the next 10 years. Mr. Metz also stressed the significant economic potential of CCS, which, in a stabilization scenario, could provide 15–55 per cent of the total mitigation effort worldwide up to 2100, while reducing mitigation costs by 30 per cent or more. However, unless the cost of CO_2 capture was 25–30 USD/tCO_2, a widespread application of the technology was not expected.

9. Mr. Larry Myer, United States of America, presented an overview of CCS technology options, focusing on CO_2 storage in oil and gas reservoirs, deep unminable coal beds and saline formations. He identified oil and gas reservoirs as early storage targets because they were broadly distributed; seals were inherent and characteristics well defined; decades of relevant technological experience existed; depressurization following exploitation provided storage capacity; and EOR and enhanced gas recovery (EGR) provided cost off-sets. One of the drawbacks of this option was the small storage capacity in long-term and abandoned wells. He emphasized that, while EOR was commercially available,[3] the technology for EGR was not well understood.

10. Mr. John Bradshaw, Australia, presented an assessment of CO_2 storage capacity from a national and interventional perspective, including a geological assessment case study for CO_2 storage perspectives in Australia, Asia-Pacific Economic Cooperation (APEC), China and the world. He outlined a risk scheme to compare and rank potential storage sites in Australia on a geological chance criteria and a calculated risked capacity. The matching of potential storage reservoirs with CO_2 emission sources in Australia showed high storage capacity in good reservoirs on the North-West shell which were, however, far from major sources; viable but not optimal reservoirs near the large emission sources; and good reservoirs in the South-East, although these required expensive offshore development. Regarding the economics of storage in Australia the pore volume of the best sites was greater than 4,100 GtCO_2, the risked pore volume was 740 GtCO_2 and if only sites that matched sources were considered, the capacity was only 100–115 MtCO_2/year based on sustainable rate or 40–180 MtCO_2/year based on cost curve rate. Mr. Bradshaw also presented an overview of highly prospective, prospective and non-prospective areas for storage at the global level and in China, that could be used as a starting point for looking for storage when matching sources and storage sites.

[3] Out of 70–80 EOR facilities only a few, such as Weyburn, use anthropogenic CO_2.

11. Panel members emphasized that while the potential for geological storage might be sufficient in general, this might not be true for all regions,[4] and potential could be reduced when economic considerations were taken into account. Saline formations that included oil and gas reservoirs as a subset[5] would provide the primary storage opportunities; the data available for oil and gas reservoirs pertinent to surrounding saline formations and much of the technology was directly transferable.[6] However, site characterization was needed to define trap, seal and reservoir characteristics. Coal seams could have additional storage potential but this option was at an early stage and the storage capacity was comparatively small.

12. With regard to storage retention time of CO_2 in sedimentary basins, petroleum systems could provide an example. Panel members said that petroleum systems stored hydrocarbons safely for hundreds of millions of years, although leakage did occur naturally and there were examples of natural catastrophic release. Several panel members also noted that, although based on limited applications, the risk of leakage from geological storage was small if appropriate storage site selection, a good monitoring programme, a regulatory system and remediation methods to stop or control CO_2 releases if they occurred were put in place. The issues of permanency of storage would depend less on the characteristics of the storage site than on the operator, regulations, safeguards, emission type and rates of injection. The risk of leakage was comparable with current leakage from EOR, natural gas storage or disposal of acid gas. While leakage could occur, it was very likely that more than 99 per cent of the CO_2 would remain in the reservoir for more than 100 years and the question of whether this was sufficient should be answered by the decision makers.

13. One panel member stressed that there was a great deal of technical advice available that could inform the application of CCS, in particular from natural petroleum systems, which was highly instructive in terms of what could be expected from CO_2 storage. There was a need to develop globally consistent technical criteria for risk assessment.

14. Participants identified monitoring as the key to assessing performance and demonstrating storage security of saline formations, and, because of similarities with petroleum systems, relevant technological experience was available for site selection, management, monitoring and remediation. A substantial portfolio of monitoring techniques was available from the oil and gas industry, including seismic and electrical geophysics, well logging, hydrologic pressure and tracer measurements, geochemical sampling, remote sensing, CO_2 sensors and surface flux measurements. The cost of monitoring for saline formations was estimated to be USD 0.17/tCO_2 injected, similar to the cost for EOR, and the cost for the subsurface component of CCS, including monitoring, was about 10 to 20 per cent of total project costs.

15. It was noted that it was difficult to predict the time period between the experimental and operational phase for CCS where thousands of projects were needed. To make a significant impact, considering the volume of emissions that needed to be reduced, the CO_2 storage industry needed to grow to several times the size of the current gas industry.

16. Answering questions, panel members indicated that the recent increase in gas prices had not been captured in the analysis in the IPCC special report on CCS. The cost of gasification for the integrated gasification combined cycle (IGCC) had been considered in the analysis; for that technology it was cheaper to add the CO_2 capture part than it was for the Gas Turbine Combined Cycle (GTCC) or

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[4] The IPCC special report on CCS indicates that it is likely that 2,000 GtCO_2 could be stored in geological storage.
[5] For example, in California 5 GtCO_2 can be stored in oil and gas reservoirs but 100–500 GtCO_2 can be stored in saline formations.
[6] Sleipner and In Salah projects are examples of storage in saline formations. At In Salah the formation contains partially hydrocarbons and partially saline water, whereas in Sleipner CO_2 is injected in a different geological unit from the hydrocarbon producing unit.

pulverized coal (PC). Therefore, IGCC might have an advantage over GTCC. In addition there was no simple way to assess how recent increases in oil prices would affect the conclusions of the special report on CCS with regard to costs, economic potential, timeliness, and availability of CCS, because there were other factors to consider.[7]

17. Discussions underlined that power plants with CCS required 15 to 40 per cent more energy to operate than power plants without CCS.[8] Mostly the energy penalty arose from capture and the challenge was to develop a capture technology that was less energy consuming. Participants noted that CCS was a mitigation technology that applied to fossil fuels and biomass and it was to be used in connection with large point sources such as power plants, petrochemical facilities and hydrogen production plants. Small units not connected to the grid were not recommended for CCS applications as they might not be economically viable.

B. Experiences of demonstration and pilot projects and other related work

1. Experiences and lessons learned from demonstration and pilot projects

18. Mr. Tore Torp, of the International Petroleum Industry Environmental Conservation Association (IPIECA) (Statoil), spoke about experiences and lessons learned from Sleipner and other demonstration and pilot projects. Mr. Torp also described the extensive previous industry experience with CO_2 that related to EOR, natural gas cleaning, transport (pipelines and ships), re-injection and underground storage,[9] soft drinks, dry cleaning and food packaging. The Sleipner project, which had started operating in 1996 in the Utsira saline aquifer, could store all the CO_2 produced by European Union (EU) power plants over 600 years. Within this project, techniques such as a 3D seismic survey had been developed to monitor the distribution of the CO_2 injected and reservoir simulation tools had been partially proven. Other demonstration projects included K12-B piloting injection of CO_2 in a depleted gas field, In Salah, Snohvit (which in 2007 was to start to inject CO_2 separated from natural gas) the Schwarze Pumpe lignite fired power plant with CO_2 capture, and Tjeldbergodden power plant with methanol plant, EOR and gas production and exporting.

19. Ms. Carolyn Preston, Canada, presented experiences and lessons learned from the Weyburn project where the CO_2 captured in Dakota was transported 300 km by pipelines and was used for EOR to produce an additional 155 million barrels of oil and store 30 million tonnes of CO_2 over the lifetime of the project.[10] The main objectives of the project had been to predict and verify the ability of an oil reservoir to securely and economically contain CO_2 (geologically) and to address the long-term migration and fate of CO_2 in a specific environment. The project had developed a comprehensive, internationally peer-reviewed data set that included a baseline monitoring survey (pre-injection); well pressures and injection and production rates should be minimum requirements for recording for any storage site. The results of phase 1 modelling suggested that the geological "container" at Weyburn was effective, as only 27 per cent moved outside the EOR area but remained within the region at 5,000 years post-injection, and therefore was suitable for long-term CO_2 geological storage.

20. Mr. Iain Wright, IPIECA (BP), highlighted experiences and lessons learned on CO_2 geological storage from the In Salah project. In Salah, an industrial-scale demonstration of CO_2 geological storage, stored some 1 million tonnes of CO_2 per annum (17 million tonnes lifetime) at an incremental cost of USD 100 million (USD 6 per tonnes of CO_2 avoided). Mr. Wright stressed that there was no commercial

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[7] The increased oil prices will affect EOR, as higher costs will be an incentive for CCS, but on the other hand the price of CO_2 goes up and may work in the other direction.
[8] PC: 25–40 per cent; GTCC: 20 per cent; IGCC: 15–25 per cent.
[9] Out of 600 sites around the globe, in 60 years only 4–5 leakages were recorded, and these were remediate.
[10] Equivalent to offsetting the emissions of 5 million cars for a year at a cost of 42 million dollars.

benefit and the project was used as a test-bed for CO_2 monitoring technologies. The joint industry research and development project had the following main objectives: to provide assurance that secure geological storage of CO_2 could be cost-effectively verified and that long-term assurance could be provided by short-term monitoring; to demonstrate to stakeholders that industrial-scale geological storage of CO_2 was a viable GHG mitigation option; and to set precedents for the regulation and verification of the geological storage of CO_2, allowing eligibility for GHG credits. The geological sediment used to store CO_2 had a good analogy with reservoirs found elsewhere (e.g. China, India and certain European countries) and the experience gained during the project could be transferred.

21. Mr. Pascal Winthaegen, Netherlands, presented experiences from ECBM projects. Mr. Winthaegen said that coal bed methane (CBM) was an option for storing CO_2 in coal seams that otherwise would not be exploited. These seams had proven capability of storing CO_2 for many years, but the estimated storage capacity for this option was much smaller than that for other options such as aquifers. Demonstration projects for ECBM were ongoing in Canada, China, Japan and Poland but they were of limited scale (25,000 tCO_2/year with an aim of increasing the storage 10 times). After some time, owing to the CO_2 injection, the permeability of the coal was reduced, resulting in a reduction of the CO_2 injection rates; for this option further work was needed to investigate absorption and disorption of CO_2 in coal seams.

22. Ms. Malti Goel, India, discussed short-term opportunities and challenges for CCS in the fossil fuel sector and presented the CCS status in India; she said that CCS was one of the technology options for carbon management being considered by the country. Ms. Goel identified three generations of clean coal technology. The first generation technologies (e.g. coal preparation, pulverized fuel, fluidized bed combustion, flue gas desulphurization, supercritical boilers) were fully deployed and commercialized. The second generation technologies (e.g. fine coal beneficiations, de-NO_x, ultra super critical boilers, circulating fluidized bed combustion, pressurized pulverized coal combustion, IGCC, pressurized fluidized bed combustion, molten carbonate fuel cells) were being demonstrated on a commercial scale; for this technology the country would need technology transfer. Finally, the third generation technologies (e.g. oxy-fuel combustion, in-situ coal gasification, coal bed methane, coal mine methane, integrated pulverized fuel, IGCC and zero emission technology, integrated gasification fuel cell, carbon capture and storage) were at an early demonstration stage and for this the country would need partners for collaborative research.

23. Various achievements of demonstration and pilot projects were discussed, including testing a variety of monitoring techniques, developing a complete, comprehensive, and peer-reviewed data set for CO_2 geological storage, contributing to establishing effective, international teams of high-quality researchers and developing best practices manuals (BPMs). Several participants noted that these projects would encourage the widespread use of technologies required for the design, implementation, monitoring and verification of a significant number of CO_2 geological storage projects. While demonstration projects focused on developing technical tools, there was also a need to develop public policy tools.

24. With regard to monitoring, discussions emphasized the need for more cost-effective tools to demonstrate long-term storage integrity and for incentives for the oil and gas industry to further develop the tools they already had. Participants pointed out that as geological formations varied greatly, monitoring technology that works in one location might not work in another and there was a need to develop a pool of knowledge for monitoring and to set standards for site certification. Monitoring was needed not only for safety reasons but also for understanding the process of injection. Participants said that the results of the tracking of CO_2 movements using seismic surveys corroborated well with reservoir simulations carried out to quantify the CO_2 in the fields. BPMs were going to be developed or updated to address protocols for activities such as storage site selection, monitoring and verification of stored CO_2,

well-bore integrity monitoring and remediation, long-term risk assessment and risk management, and maximizing economic CO_2 storage capacity.

25. It was observed that the EU was spending EUR 140 million over 4–5 years for a variety of research projects that were contributing to preparations for large-scale implementation of CCS, for example the ULCOS (ultra low CO_2 steelmaking project) initiative of the steel industry that could result in capture costs lower than those for power stations. Several participants mentioned international collaborative efforts on CCS such as the Carbon Sequestration Leadership Forum (CSLF), Future Gen,[11] BIG SKY Carbon sequestration partnership and the Asia Pacific Partnership in Clean Development. Activities included collaborative research on basalt rock studies under a CSLF project initiated by USA[12] and feasibility studies in oil fields for enhanced recovery and saline aquifers. One developing country participant said that the high costs of capture and storage required the establishment of a financial mechanism.

26. The main requirements of CCS by authorities and the public were also discussed. While authorities would have requirements similar to those regulating oil and gas fields (e.g. access rights and licence, site characterization and plan, monitoring and verification, remediation, decommissioning and monitoring until stability) plus reporting requirements (reporting to UNFCCC and the emissions trading scheme (ETS)), the public would demand safety (e.g. safe operation, no leakage, transparent monitoring and verification, acceptance from UNFCCC and ETS, long-term stability).

27. Several participants identified the main tasks envisaged for the demonstration projects, including developing BPMs, influencing the development of clear and workable regulations for CO_2 storage, building upon existing effective regulatory frameworks, and influencing the development of an effective public consultation process and of an effective public policy to seed the development of a large and economic CO_2 supply and infrastructure and of a mechanism for monetizing credits for CO_2 storage.

28. With regard to future work, it was necessary to reduce the capital cost for CO_2 capture and increase its efficiency (e.g. target USD 20–30 per tonne of CO_2) and to build trust in storage by addressing the issue of permanency, and by sharing experiences, methods and tools developed by the oil and gas industry for EOR. Some participants also underlined the need to initiate large-scale demonstration projects and to develop regulatory and policy frameworks, including incentives to make this option attractive (e.g. eligibility for mechanisms such as the clean development mechanism (CDM) and EU ETS).

29. General discussions that followed addressed issues such as barriers resulting from additional costs associated with this technology, the uncertainty about caps in Parties included in Annex I to the Convention (Annex I Parties) and the lack of caps in Parties not included in Annex I to the Convention (non-Annex I Parties). With regard to additional costs several views were expressed: cost should be reflected in the final products;[13] CCS costs were low compared with other technologies that could address climate change, and it was available today; and EOR could be profitable, including in the many developing countries where opportunities existed for EOR. It was observed that the costs per tonne of CO_2 avoided that were mentioned for the demonstration projects presented in the workshop were relatively low and these projects could benefit from incentives offered by CDM (In Salah) and joint implementation (JI) (Weyburn).

[11] An initiative to build the world's first integrated sequestration and hydrogen production research power plant (275 MW zero emission power plant).
[12] The results on mineral trapping studies would be useful for other countries having similar formations.
[13] Similar to the steel industry where abatement costs have been included in the costs of final products or electricity generation where the costs of reducing SO_x emissions are reflected in tariffs.

30. With regard to long-term monitoring, criteria for site selection and future projected leakage rates, panel members showed that the estimated leakage rate in Sleipner was expected to be zero for some thousands of years. However, in view of the fact that human systems might malfunction and because of the geological uncertainty, some contingency plan was needed. A call was made for site certification standards and it was observed that the industry was working on such standards. In the Weyburn case, the site had been selected, inter alia, for its good record on man-made interventions in the reservoir and the well-understood geology of the area. Based on the results of the project, which showed good integrity of the reservoir, leakage was not anticipated to be a problem. To date no leakage had been recorded and, although monitoring would not necessarily need to continue, it was still being done to reassure the public.

31. Several participants asked how the costs of monitoring compared with the total costs of CCS. In the Sleipner case 17 USD/tonne CO_2 avoided (not including capture which was done anyway to sell the gas) was needed[14] and monitoring costs had been 0.1 USD/tonne CO_2 avoided. A recent study indicated that for a large-scale operation these costs would be 0.5 USD/tonne CO_2 avoided even for monitoring for many years after stopping injection.

2. Non-governmental organizations' perspectives

32. Mr. Haroon Kheshgi, business and industry non-governmental organizations (IPIECA), outlined an industry perspective on CCS. The main advantages of CCS included global distribution of geological storage sites that made CCS potentially applicable worldwide, the potential to address large CO_2 sources – primarily in the power sector – and that CCS would allow coal to continue to contribute to energy in a GHG constrained world. To fulfil its promise CCS would need to be used beyond EOR in the power sector, and to become commercially widespread it would require a policy to address added costs to make it economically viable and an adequate regulatory and legal framework. A diverse set of initiatives by academia, governments and industry – the petroleum industry in particular – was improving the performance and prospects of CCS by accumulating commercial experience with gas injection; through research initiatives to find lower-cost CCS technologies and improve understanding of risks; and by assessing the merits of CCS as well as other technology options that provided valuable information for decision-making and a basis for public acceptance.

33. Ms. Gabriela von Goerne, Greenpeace, presented an environmental non-governmental organization perspective on CCS. She spoke of the vision of a low carbon world, where everyone had access to clean water, food and energy supplies, driven by new renewable energy and energy efficiency that reduced demand; CCS involved continuing to burn coal and, instead of avoiding the production of harmful emissions, it buried them. She outlined environmental concerns about storing CO_2 such as liability, regulatory and accounting issues, monitoring, risk of leakage[15] and contribution to sustainable development. With regard to the latter, power plants with a CO_2 capture facility needed more coal and produced more CO_2 than conventional plants, resulting in more land degradation at mining sites. Future generations would pay the price by being locked in a fossil-fuel path with no other option than to store millions of tonnes of CO_2 underground. Therefore, long-term structural changes were needed to reduce the dependency on fossil fuels and increase the use of renewable energy. Moreover, the IPCC special report had stated that CCS would not play a major role until the second half of the century and therefore could not help with the urgent need to cut emissions now.

34. Discussions and presentations in this session highlighted the industry's experience in achieving safe geological storage of CO_2 by site selection and risk management systems that made use of information from site characterization, operational monitoring, scientific understanding and engineering

[14] It should be noted that these costs are in general three times greater for off-shore than on-shore projects.
[15] Storage performance of CO_2 in geological reservoirs has not yet been proved to be safe over a long period of time.

experience. Participants spoke of the important role of policies to address the added costs and make the technology competitive, including incentives at national and international levels, the need for industry to make efforts to consider a business model for CCS, and the need to test CCS on a commercial scale for power generation.

3. Innovation, deployment, diffusion and transfer of CCS technologies

35. Ms. Trude Sundset, Norway, said that the goal of the CSLF was to ensure that CCS became a viable tool to achieve the long-term stabilization of atmospheric greenhouse gases. The method used by CSLF was to coordinate research and development with international partners and private industry; CCS applications would depend on a wide range of technical, geological, economic and institutional factors and a robust global technology could be created only by serving such a wide range of needs and involving countries with diverse perspectives. The initiative had brought together engineers, scientists and politicians, who worked in policy and technical working groups. Ms. Sundset said that collaboration created substantial benefits, including solving problems faster, reducing costs to each participant, stimulating creativity and learning from each other and using complementary capabilities to solve problems.

36. Mr. Xuedu Lu, China, said that in China experiences with CCS were limited to several experimental EOR projects and research on post-combustion and pre-combustion carbon capture technologies conducted in academic institutes. An initial estimation had shown that China had CO_2 storage potential in 46 oil and gas reservoirs (7.2 billion tonnes of CO_2) and in 68 unminable coal beds (12 billion tonnes of CO_2). With regard to cooperation activities, China and the United Kingdom had signed a memorandum of understanding (MoU) on cooperation on a near-zero emission power plant through CCS that covered developing knowledge and expertise in the technology, assessing CCS potential, identifying opportunities for demonstration and deployment in China, reviewing costs and economics of CCS in China and options for financing research and development. China and the European Commission had signed another MoU on near-zero emission power generation through CCS that covered exploring the options for zero emission coal technology through CCS in China, defining and designing a demonstration project and the construction and operation of a demonstration project. Other cooperation activities included Geo-Capacity[16] and COACH.[17] Mr. Lu stressed that domestic and international policy and financial support was needed to develop the technology and in order to participate effectively in its development endogenous capacity-building was needed.

37. Mr. John Gale, International Energy Agency (IEA) Greenhouse Gas Research and Development Programme, identified two challenges for a widespread use of CCS: development of post-combustion capture of CO_2 for power generation (3–5 million tonnes CO_2 per year demonstration projects) and expansion of the pipeline infrastructure to a size comparable to that of natural gas. Neither of these challenges presented a major technical barrier. With regard to containment Mr. Gale said that there was no firm evidence from any of the large-scale projects[18] that seepage[19] was occurring but monitoring had been carried out over short periods (3 to 25 years) and there was a need to demonstrate that no seepage would occur for hundred of years (fossil fuel dominance period). Performance assessment studies, which could be used to further investigate this issue, suggested negligible seepage.[20] However, there was no

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[16] An EU project coordinated by the Geological Survey of Denmark and Greenland. In total 26 partners, but Tsinghua University is the only Chinese partner.

[17] Cooperation Action within CCS China-EU: coordinator: Institute of French Petroleum, 21 partners in total, including Chinese partners.

[18] Sleipner, Weyburn and Rangeley.

[19] The term "leakage" has a different meaning for CDM and "seepage" is therefore proposed to be used.

[20] Weyburn simulations suggest 5,000 years before surface seepage theoretically could occur. Sleipner modelling suggests all CO_2 will have dissolved after 3,000 years.

technical basis on which to quote a seepage rate for geological storage or to discuss generic seepage from storage sites. Storage sites could be designed for zero seepage and the approach should be to ensure that this was realized[21] and to account for seepage, should it occur. Investment in CCS in the oil and gas sector might be stimulated by high oil and gas prices and CCS costs would reduce by 20 to 40 per cent with replication. Mr. Gale also pointed out that many CO_2 emission sources were in developing countries and their number was projected to rise. Therefore, technology transfer and implementation in developing countries was needed and measures to remove barriers to technology transfer and diffusion should be addressed. Mr. Gale said that CCS should also be allowed under CDM to stimulate its market take-up.

38. It was pointed out in the general discussions that followed that renewable energy sources and CCS were complementary, as CCS would make it possible for more intermitted energy sources, such as renewables, to penetrate the market and that the European Commission was providing funds to carry out research on storing renewable energy that would address the issue of intermittency.

C. Capacity-building for the development of carbon dioxide capture and storage technology and other related issues

1. Capacity-building through education and outreach

39. Mr. Bill Reynen, Canada, presented activities on the development and deployment of CCS training modules and courses to build awareness and capacity, drawing on the work done by the Delphi group, in particular within a project established by the APEC Energy Working Group. The three-phase project had been designed to help non-industrialized member economies successfully identify, evaluate and develop prime CO_2 capture and geological storage projects in their countries. Phase I had produced an inventory and assessment of potential geological sites for storing CO_2, including an overview of CO_2 emissions and type of storage option available and a Geographical Information System.[22] Phase II focused on enhancing capacity of APEC economies through the use of training materials and workshops,[23] building awareness and capacity around the potential for the capture and geo-storage of CO_2 and contributing to sustainable development objectives. Phase III was dealing with enhanced capacity-building and enhancing existing training materials, identifying opportunities that CO_2 capture and geological storage represented for economies in the region and increasing the ability to evaluate options and implement successful CCS initiatives.

40. Mr. Arthur Lee, IPIECA (Chevron), highlighted industry experiences in capacity-building for demonstration and use of CCS and for transfer of knowledge of CCS to decision-makers. Noting that CCS was being advanced by a diverse set of initiatives and was accumulating commercial experience, costs were reduced and risks were better defined and managed, Mr. Lee stated that continued, long-term research and development (R&D) investment would be key to improving CCS ability to deliver energy for development while managing carbon risk. He identified the following issues as a priority for the industry's work on CCS:

(a) Legal and regulatory issues: potential classification of CO_2 as waste in pre-existing regulations, long-term liability and monitoring;

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[21] For example a regulation process that includes: effective site characterization (geology, hydrogeology, faults and wells), risk assessment, monitoring programme (pre- and post-injection, remediation planning).

[22] Includes data on project area, political/province boundaries, point source emission data by node, major geological provinces, major petroleum basins (productive and non-productive), sedimentary basins with high, low and no "prospectivity" for CO_2 storage, coal distribution and coal type in East and South-East Asia.

[23] The APEC training package is available at <fttp://www.delphi.ca/apec/>.

(b) Industry strategies: relationship to CO_2 sources in the power industry, development of a potential business model, the role of IPIECA (e.g. best practices, facilitate government interaction) and impact on current operations;

(c) Develop incentives: importance of CCS in CDM and crediting, R&D incentives;

(d) Transfer knowledge of CCS to policymakers in climate change policy: communicate the industry's goals, assess how CCS fitted into a business portfolio, the role of CO_2 EOR and early opportunities;

(e) Public acceptance and outreach on CCS.

41. Mr. Lee also identified a potential conundrum for industry and governments: industry was waiting for the development of regulations before implementing CCS activities, while governments were waiting for industry experience and best practices before they would produce regulations. He suggested that commercial readiness with widespread deployment was the way forward and a favourable business climate needed to be established. A CO_2 infrastructure should be developed, to include integrated regional CO_2 transport networks. The role of companies and governments in building and operating those networks would call for policy developments.

2. Inventory, regulatory and legal issues

42. Mr. Simon Eggleston, IPCC, expressed the view that the *2006 IPCC Guidelines for National Greenhouse Gas Inventories* (2006 GL) gave a complete methodology for CCS that was consistent with the remainder of the 2006 guidelines. The 2006 GL provided guidance for the capture and transport of CO_2 and for geological storage.[24] While emissions associated with CO_2 capture should be reported under the IPCC sector in which capture took place, emissions from transport, injection and storage of CO_2 were covered under the source category 1C. The "Tier 3" method was used for capture, as it was based upon measurement that could be done either by measuring residual emissions to atmosphere or estimating emissions based on fuel carbon contents and subtracting the measured amount captured. Concerning transport of CO_2, Mr. Eggleston highlighted pipelines, shipping, rail and road. The guidelines for pipelines provided default "Tier 1" emission factors and a more detailed method to derive emission factors from factors for fugitive methane from pipelines and associated equipment. With regard to injection all equipment at the well head was included and measurements at the wellhead of the injected fluid included the flow rate, temperature and pressure. As regards estimation, verifying and reporting emissions from CO_2 storage sites, the guidelines did not provide emission factors and they relied on site characterization,[25] assessment of risk and leakage, monitoring and reporting. Complete national reporting included CO_2 from capture in the country; CO_2 leakage from all transport and injection in the country; CO_2 leakage from all storage sites in the country; and imports and exports of captured CO_2. Quantities of CO_2 for later use and short-term storage should not be deducted from CO_2 emissions. Leakage from storage and pipelines should be reported in the country in which they occurred and for storage sites crossing borders they should be reported in the country which administered the storage.[26]

43. Mr. Jürgen Lefevere, European Commission, spoke about EU research into CCS, recent EU based industry initiatives and activities towards developing an EU enabling policy framework on CCS. On EU research, Mr. Lefevere said that the EU 5th and 6th Research Framework Programmes included a project portfolio on CCS that was worth more than EUR 170 million; research funds were also being

[24] No emissions estimation methods are provided for any other type of storage option such as ocean storage or conversion of CO_2 into inert inorganic carbonates.
[25] Geology of storage evaluated and local regional hydrology and leakage pathways have been identified.
[26] In principal: Capture + Imports = Injected + Exports + Leaks.

provided for other energy sources and the amounts for CCS were a balanced part of the total. Mr. Lefevere highlighted recently announced industry-led CCS initiatives in the EU, including a thermal oxy-fuel pilot coal power plant with CO_2 capture, a power plant with H_2 as fuel, a natural gas power plant with CO_2 capture and transport for offshore injection and EOR, and an IGCC power plant with CO_2 capture and storage. The Commission was actively linking its internal work with international initiatives; examples included participation in the CSLF, the EU–China initiative and collaboration with the Organization of the Petroleum Exporting Countries (OPEC). With regard to an enabling policy framework, a working group on CCS had been initiated under the European Climate Change Programme to explore geological carbon capture and storage as a mitigation option. This involved reviewing the potential, economics and risks of CCS, identifying regulatory needs and barriers, exploring the elements of an enabling regulatory framework for the development of CCS, and identifying other barriers that could impede the development of appropriate policies to advance CCS. The final report of the working group, to be considered by the Commission Communication in 2007, might include a proposal for EU-wide legislation on CCS. This EU Policy and Regulatory Framework might include assessment of risks and environmental impacts, permitting of CCS activities, short and long-term liability and incentives for CCS, including the role under the EU ETS.

44. Recent developments on international marine treaties relating to CCS were presented by Ms. Elizabeth Hattan, UK. Ms. Hattan said that CCS raised wider environmental issues, in particular on potential impacts on marine environment. With regard to the Convention on the Prevention of Marine Pollution by Dumping Wastes and Other Matters (London Convention) and its Protocol, it had been acknowledged at the 27th consultative meeting (2005) that CCS had a role as part of a suite of measures to tackle climate change and ocean acidification. She pointed out that, if it was accepted that the London Convention did cover the sub-sea bed, CO_2 injection would not be permitted. While Parties recognized that they had differing interpretations of the Convention and its Protocol, they had decided that it was necessary to clarify those interpretations with a view to facilitating and regulating CCS, and intersessional legal and technical working groups had been established. The legal group had met and agreed that there was a need to bring CCS into the Protocol and to regulate it as well as facilitate it, and had proposed an amendment, for consideration at the next Consultative Meeting, that would add CO_2 to an annex to the Protocol, so allowing it to be dumped, subject to certain conditions, including that disposal had to be in sub-sea bed geological formations, a CO_2 stream had to consist overwhelmingly of CO_2 and there was no added waste. Ms. Hattan said that a process was in place for amending the London Convention and its Protocol, in addition to developing guidelines on the operation of CCS projects. If these amendments and guidelines were adopted they would result in a robust international marine framework that would not act as a barrier to CCS projects.

3. Understanding the risks associated with CO_2 capture, transport and storage

45. Mr. Wolfgang Heidug, IPIECA (Shell), gave a high-level overview of storage technology and issues. He highlighted two types of geological storage risks:[27] global (CO_2 going back into the atmosphere) and local (elevated gas-phase concentrations in the near-surface environment; effects of dissolved CO_2 on groundwater chemistry; effects that arose from the displacement of fluids by the injected CO_2). Noting that geological storage performance depended on a combination of physical and geochemical trapping, Mr. Heidug outlined four trapping mechanisms[28] and presented various ways in which CO_2 could leak, including CO_2 escaping through a gap in a cap rock into a higher aquifer and CO_2 escaping via poorly plugged abandoned wells (corroding cement). To mitigate CO_2 leaks, risk

[27] Risks are proportional to the magnitude of potential hazard and probability that these hazards will occur.
[28] Structural and stratigraphic trapping; residual CO_2 trapping (blocks due to capillary forces); solubility trapping (in water and becomes heavier) and mineral trapping. Over time, residual CO_2 trapping, solubility trapping and mineral trapping increase.

management was used to address issues relating to site selection, risk assessment, monitoring and verification, and remediation planning. In terms of time horizon, risk management considered pre-injection (characterization of the site; long-term risk assessment; monitoring; remedial measures); operation (short-term prediction; monitoring of the site to verify the prediction); abandonment (update of long-term assessment; deciding on duration of site-specific monitoring); and post-abandonment (update of assessment and transfer of liability-site-specific monitoring, if necessary). A variety of monitoring technologies existed and specific techniques should be selected to target the leakage scenarios developed. Monitoring should be tailored to specific conditions and risks at storage sites; techniques included sensors for measurement of CO_2 in air, geochemical downhole sampling, well logs and geophysical techniques (seismic, electromagnetic, gravity).

46. Ms. Preston addressed issues relating to monitoring the geological storage at Weyburn. She outlined the main components of the risk management process, including risk analysis and risk assessment sub-processes. The objectives of risk assessment activities at Weyburn were as follows: apply risk assessment techniques to predict the long-term fate of CO_2 within the storage system; identify risks associated with geological storage; assess ability of oil reservoirs to securely store CO_2; derive amount of CO_2 being stored in the Weyburn reservoir as a function of time; explore consequences of any leakage; and provide assessment results primarily in terms of flux of CO_2 from the geosphere as a function of time. She emphasized that in the final phase of the risk assessment at Weyburn a balanced approach that was open to scrutiny would be taken. This phase might include conducting a peer review evaluation of the base and alternative scenarios, updating and refining the geosphere model, conducting a semi-quantitative risk assessment for Weyburn and Midale, using experts and stakeholders to provide opinions on the likelihood and consequences of various impacts due to leakage at Weyburn, and conducting a full-field risk assessment at Weyburn and Midale.

47. It was emphasized during the discussions and presentations that the risks associated with CO_2 capture and transport were fairly well understood. Regarding capture, these risks were similar to regular health and safety and environmental risks in industrial operations, while the risks involved in transport were comparable to or lower than the risks relating to hydrocarbon pipelines. Several elements were identified that would comprise a good storage site. First, stratigraphy factors – the side should have a cap rock with low permeability, large thickness, lateral continuity and absence of faults and should be a storage formation with high permeability and large thickness and be areally extensive. Second, geomechanics factors – the site should be tectonically stable with favourable stress conditions on faults and fractures. Third, geochemistry factors – the site should have mineralogies that buffered acidity increase and promoted trapping as an immobile solid phase. Finally, anthropogenic factors – if the site had abandoned wells their location and condition should be known. With regard to the long-term risk assessment, panel members said that one of the most relevant risk assessment methods was based on the systematic compilation of features, events and processes at the site (FEP method). "Features" related to any characteristic of system components boreholes, lithography or nearby communities. "Events" were particular happenings such as pipe fracture, earthquake in the vicinity or meteorite impact. "Processes" were natural phenomena such as corrosion of casing, dissolution of packing material or convection of groundwater. In risk assessment, FEP identification was followed by classification, ranking, screening and interaction, grouping and selection, and potential leakage scenario development. For each leakage scenario remedial measures were identified.

IV. General discussions

48. It was mentioned that the UK had six CCS projects, with a capacity of around 4,000 MW, which could be considered as an act of good faith in anticipation of robust regulatory measures to be put in place not only by the Government of the UK but also by the EU. With regard to the long-term liability for storage, a transfer of the liability to Government would make CCS difficult to accept and one option

would be to create a body operated on commercial basis. This operator could access incentives through CDM or EU ETS and would be responsible for a period of time. However, ultimately the responsibility had to be reverted to the public domain primarily because the longevity of the commercial institutions concerned could fall short of the time frame for ensuring integrity of the reservoir. Because there was a reward to the operator there should be a regulated process to transfer the liability from the private to the public domain (e.g. required to show that trapping had occurred, that the CO_2 in the subsurface was behaving as predicted by the models, and that risk assessment had been done and there was no leakage to be expected in the centuries to come).

49. Participants exchanged views on how to draw on work done by the EU to establish their national frameworks. Several issues with regard to regulatory and policy framework had been discussed, including industry concerns that such frameworks might hinder the development of CCS; how to harmonize existing national and international legislation on storage of natural gas, mining laws, existing permitting and environmental impacts assessment rules with CCS frameworks; how to identify hindrances to CCS projects; and the need to create additional incentives for CCS projects.

50. Replying to the question on whether CCS would be in phase two of EU ETS, a panel member stated that if new legislation for CCS was needed then it would go into the EU regulatory process for assessing its impacts, which could take up to two years. Participants asked how far the capacity-building for APEC addressed complex issues such as national inventories, risk assessment and management, and CDM and other incentives. The reply was the work done was a quick start to broadening the information base in developing countries, helping to raise awareness of CCS in key people in emerging economies. However, more work was needed to improve and further develop this training material.

51. Stressing the high quality of the IPCC special report on CCS and the IPCC 2006 GL, one participant from EU said that CCS was a mitigation option in a portfolio of options that could contribute to achieving the objective of the Convention as long as projects were developed and managed in a safe and reasonable manner. Emissions, including any physical leakage from CCS operation, should be accounted appropriately under the UNFCCC and the Kyoto Protocol; the EU did not support CCS involving storage in the ocean because presentations and the IPCC special report had indicated that this storage was not permanent and there were uncertain impacts on the marine ecosystem.

52. With regard to the complementarity of different mitigation options and the relationship between investment in CCS and in other mitigation technologies, participants felt that investment in other mitigation technologies, in particular efficiency and renewables, should certainly not be lessened owing to investment in CCS; CCS came in at a certain price for CO_2 and that it was important to create incentives for this technology to come onto the market. Several participants noted that the chapters of the IPCC 2006 GL on CCS presented at the workshop were meant for national inventories and that site specific guidance could be applied at site specific levels. They also noted that the guidelines addressed the reporting but not the accounting issues, in particular the transboundary transfer of CO_2 in association with CCS.

53. Participants noted the key role of site selection and good planning and management of projects as well as the importance of standards for site selection and site management and raised the issue of considering the needs for international work on such standards and guidance. Furthermore, it was important for the potential leakage rate to be predicable if there was to be public acceptance of CCS.

54. It was pointed out that, according to Article 6 of the London Protocol, it was not possible to export waste or other matter to other countries for dumping or incineration at sea and that the implication of these provisions on CCS would not be discussed at this stage, as it required the amendment of the Protocol itself. Participants discussed issues relating to reporting CCS in national communications and mentioned the model of Norway’s communication. One participant said that Canada was still developing

a reporting strategy for the Weyburn project. One panel member from the EU stressed that national legislation took precedence (permitting regimes, environmental impact assessments, public awareness, access to information, incentive and how it qualified under EU ETS) and that meant assessing whether there were any obstacles in EU legislation that could hinder CCS projects. Another participant recommended that IEA prepare lists of experts that might be available for helping countries to address issues relating to CCS in their national inventories and that the UNFCCC secretariat update its roster of experts to include such experts.

55. Several participants thanked panel members for their presentations, noted the diverse participation in the workshop, the expertise available in the room and the value of the dialogue, and said that the workshop had provided a great learning opportunity for Parties to exchange views on CCS issues.

56. In his summary, Mr. Kumarsingh spoke of the good presentations ranging from experiences in countries, capacity needs for CCS, inventories and regulation to risk management and monitoring. He noted that limited experience of CCS existed in developing countries and stressed the need to deploy CCS and the associated need for appropriate regulatory frameworks. While industry was working on good practices and standards for selection of geological storage reservoirs there was a need to work with governments to establish realistic standards and codes. He said that much work needed to be done to ensure that the potentially large and rapid scale-up in the deployment of CCS could be safely accomplished. In this regard he emphasized that the next 5 to 10 years constituted a critical window for research and field experimentation before large-scale commercial adoption of CCS technologies began. Mr. Kumarsingh said that several concerns regarding the relation between CCS and CDM had been touched upon and would be addressed at a workshop on carbon capture and storage as CDM project activities to be held on 22 May; he thanked panel members and participants for their active participation.

V. Issues for further consideration

57. From the presentations and discussions during the in-session workshop, several issues that emerged for further consideration are presented below, and are not in any order of priority:

(a) Initiate additional pilot and large-scale demonstration projects, including for the power sector (e.g. coal gasification combined with CCS) with storage sites in different geological settings to refine costs, gain experience at a regional level, and gain confidence in the security of geological storage. Develop best practices manuals as a practical and technical guide for design and implementation of CO_2 storage associated with EOR;

(b) Research and development to bring down the costs, in particular the costs associated with CO_2 capture, and increase capture and overall efficiency (e.g. target USD 20–30 per tonne CO_2);

(c) Build trust in storage by addressing the issue of permanency, by sharing experiences, methods and tools developed by the oil and gas industry for EOR and by establishing standards and guidelines for site selection and site management (industry and governments);

(d) Develop regulatory frameworks that address site selection, risk assessment and long-term monitoring. Develop regulations for CO_2 storage building upon existing effective regulatory frameworks that may promote consistent and environmentally sound approaches to CCS across the world;

(e) Promote effective public policy to seed the development of a large and economic CO_2 supply and infrastructure as well as mechanisms for monetizing credits for CO_2 storage;

(f) Identify and promote incentives to make this option attractive (e.g., policy frameworks, market eligibility for mechanisms such as CDM and EU ETS) and remove barriers to technology transfer and diffusion.

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