Annex 4

IMPLICATIONS OF THE INCLUSION OF GEOLOGICAL CARBON DIOXIDE CAPTURE AND STORAGE IN AS CDM PROJECT ACTIVITIES

An assessment
Final Report
A report for the UNFCCC

[Texts underlined are recommendations]

Contents

List of Tables

List of Figures

A. Introduction

1. The purpose of this report is to assess the implications of the possible inclusion of carbon dioxide capture and storage in geological formations as clean development mechanism project activities, taking into account technical, methodological, legal, environmental and market issues. The main issues were identified by the CDM Executive Board (hereinafter referred to as the Board) in their report of the twenty-sixth meeting (Annex 13)[1]. These main issues and options to resolve them were considered comprehensively in two UNFCCC Synthesis Reports[2,3] (The 'First' and 'Second' Synthesis Reports) as a result of the considerable work contributed by Parties and others in their submissions on this issue. This report seeks to draw conclusions from the issues and options in these Synthesis Reports, drawing upon more recent developments, including regulatory developments, and reports and the authors' expertise.

2. The EU Directives for the European Union Emission Trading System and for geological storage of carbon dioxide are part of the most comprehensive regulatory framework in the world today where geological carbon dioxide storage is regulated and integrated with emissions trading. Against this background, the report draws extensively on experiences from the EU regulation. It should be noted that there are several other regulatory frameworks covering carbon dioxide capture and storage emerging around the world which provide valuable examples and experiences and will continue to do so in particular as they develop.

3. Throughout the considerations, deliberations, conclusions and recommendations in this report, the primary underlying context is the protection of the environment. This has two aspects. One recognising the positive benefits of carbon dioxide capture and storage (CCS) as one of the potentially significant mitigation options to address climate change. The other recognising that CCS must only be undertaken in a way that does not compromise this primary benefit or cause harm in terms of the local environment and human health.

4. The structure of the report is based upon the Terms of Reference (ToR)[4] paragraph 5, with additional issues identified from EB26 and the Synthesis Reports included.

[1] UNFCCC/CCNUCC EB26 Annex 13.

[2] FCCC/SBSTA/2008/INF.1, Synthesis on views on issues relevant to the consideration of carbon dioxide capture and storage in geological formations as clean development mechanism project activities.

[3] FCCC/SBSTA/2008/INF.3, Synthesis on views on technological, methodological, legal, policy and financial issues relevant to the consideration of carbon dioxide capture and storage in geological formations as project activities under the clean development mechanism.

[4] UNFCCC/CCNUCC EB47 Annex 11.

B. Summary for Policy Makers

Technical issues

5. Carbon dioxide capture and storage (CCS) is a three-stage process consisting of the capture of carbon dioxide (CO_2), the transportation of CO_2 to a storage location, and the long term isolation of CO_2 from the atmosphere.

6. The maturity of CCS technology is a complex issue since there is a number of competing technologies at various stages of development and commercialisation within each stage of the process. However, the IPCC Special Report on Carbon Dioxide Capture and Storage ("IPCC SR") has concluded that complete CCS systems can be assembled from existing technologies that are mature and economically feasible under specific conditions.

Feasibility of CO_2 Capture

7. CO_2 separation from other exhaust gases in a gas stream involving the use of liquid solvents has been in operation for over a half century, with 100's of plants currently operating worldwide. For example, CO_2 separation is applied in some chemical industries and natural gas processing as an inherent part of the production process, but in many cases the separated CO_2 is vented to the atmosphere. However, the application of CO_2 separation technologies to CO_2 from flue gas mixtures exiting combustion processes is costly and has not been widely applied, and remains to be proven at the scale and composition of gases applicable for large power plants.

8. CO_2 capture involves CO_2 separation, compression and dehydration for transport and storage. CO_2 capture and subsequent transportation over shorter or longer distances have been commercially applied for several decades to generate CO_2 streams for various uses and the first large-scale CO_2 capture projects solely for CO_2 emission mitigation purposes have been taken into operation since the mid-1990's. Because of the low value of the CO_2 product, this occurs primarily for emission sources where CO_2 can be captured at a relatively speaking low additional cost, e.g. where CO_2 separation is already implemented as part of the production process.

9. Due to reasons related to economies of scale, CCS for the purpose of CO_2 emission mitigation is most likely to occur in connection with large point emission sources. Within this restriction, CCS may be applied to mitigate CO_2 emissions from a range of point sources, each with specific characteristics.

10. There is a range of technical options for CO_2 capture, each with its specific range of applications and technological features and readiness. Extensive development work remains to create the necessary conditions for the widespread deployment of CO_2 capture under conditions that prevail in major emitting sectors, notably the power sector and a range of industrial sectors. Intensified development aims at fostering improved capture technologies for such emission sources so as to reduce the cost of CO_2 capture and thereby mitigate a significant techno-economic hurdle.

CO_2 transport

11. Main options for CO_2 transportation are pipelines and ships. Transporting CO_2 in pipelines is an established technology with approximately 5 600 km of long-distance CO_2 pipelines globally, annually handling over 50 million tonnes CO_2 from anthropogenic and natural sources. Risks related to CO_2

transport are associated with leaks and the accumulation of CO_2 in low-lying areas where it can create a health risk or even be fatal at high concentrations. Mitigation approaches exist and up to 2006, pipeline transportation of CO_2 shows a lower rate of fugitive emissions per kilometre of pipeline than natural gas pipelines. Ship-based transportation of CO_2 has similarities with transportation of liquefied petroleum gases that are transported on large commercial scale today. The selection of CO_2 transportation method would be made on a case-by-case basis, taking both the relative economics of alternatives and practical considerations into account.

Final storage of CO_2 in geological formations

12. Geological CO_2 storage is accomplished by injecting the captured and transported CO_2 in a dense form ("supercritical" state) into suitable deep rock formations and can be undertaken in a variety of geological settings in sedimentary basins - onshore or offshore. Oil and gas reservoirs, deep saline formations and deep, unmineable coal beds represent promising opportunities for geological CO_2 storage. CO_2 storage in oil and gas reservoirs can take place in depleted reservoirs or in partially depleted reservoirs for so-called enhanced hydrocarbon recovery (EHR).

13. Many of the technologies required for large-scale geological storage of CO_2 have already been developed in the oil and gas exploration and production industry and are being practiced with some adaptations in current CO_2 storage projects.

14. Once the CO_2 is injected into a storage formation the CO_2 can diffuse through the pore spaces of the rock formation and become trapped by one or more of several trapping mechanisms. The onset of trapping mechanisms depends on geology and time, see Figure SPM1.

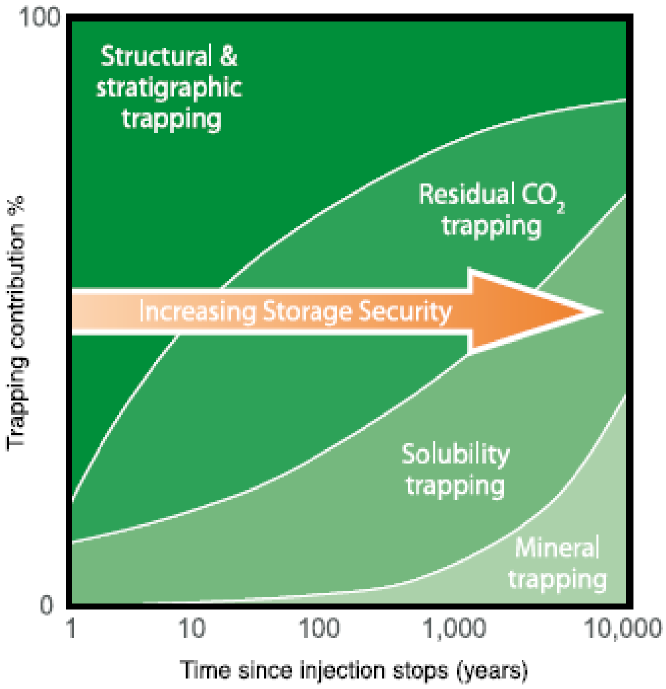


Figure SPM1: Trapping mechanisms in geological storage over time (Source: IPCC Special Report on Carbon Capture and Storage (2005), Chapter 5, Figure 5.9.

15. The IPCC has assessed minimum expected CO_2 retention levels for appropriately selected and managed formations and concludes, based on observations and analysis of current CO_2 storage sites, natural systems, engineering systems and models, that the fraction retained is very likely to exceed 99% over 100 years, and is likely to exceed 99% over 1000 years. The IPCC SR furthermore concludes that similar fractions retained are likely for even longer periods of time, as the risk of seepage is expected to decrease over time as other mechanisms are activated.

16. The characteristics of geological formations differ and their suitability for long-term CO_2 storage depends strongly on their individual properties. Therefore, detailed characterisation including identifying and quantifying relevant properties of the formation, determining its capacity to trap CO_2 and assessing site-specific risks of potential long-term seepage is a requirement for appropriate site selection. Techniques developed for the exploration of oil and gas reservoirs, natural gas storage sites and liquid waste disposal sites are suitable for characterizing geological storage sites for CO_2.

17. Comprehensive syntheses of the current knowledge base with respect to site characterisation and selection can be found in the IPCC SR and the 2006 IPCC Guidelines for National Greenhouse Gas Inventories ("2006 IPCC Guidelines"), including a recommended approach to site characterisation and selection. Institutional and legal experiences are emerging and practical applications of the IPCC syntheses of information and the recommendations can be found in, inter alia, amendments to the London

Convention and the OSPAR Convention as well as the EU Directive on geological storage of carbon dioxide.

18. The First and Second UNFCCC Synthesis Reports[5] [6] reflect a broad agreement in Parties' submissions that site characterisation and selection is the most critical element in ensuring long-term or permanent CO_2 storage.

19. It is recommended that any CCS project activities approved under the CDM should be located to secure sites and operated according to best practice. If CCS is considered eligible under the CDM, it is therefore recommended that the Board should develop criteria for the assessment of site selection and approval, including risk assessment, drawing on the existing knowledge base. For any proposed geological CCS CDM project activities, the site characterisation and selection process should be fully described.

20. The validation of the site characterisation and selection would require a DOE with appropriate CCS expertise.

21. The IPCC SR states that careful storage site design and operation, together with methods for early detection of seepage, are effective ways of reducing hazards associated with diffuse seepage. A framework for monitoring of geological CO_2 storage projects is provided in the 2006 IPCC Guidelines. In addition, experience of monitoring geological CO_2 storage is accumulating from existing research and demonstration activities. The IPCC SR furthermore provides an overview of remediation options for a range of seepage scenarios. Possible remediation measures are furthermore highlighted by the two Synthesis Reports. These techniques could involve standard well repair techniques or the extraction of CO_2 by intercepting its leak into a shallow groundwater aquifer.

22. Based on the submissions of Parties and organisations, the First and Second UNFCCC Synthesis Reports underline that proper management of CCS projects is of utmost importance in minimising seepage, as well as fugitive emissions from CO_2 capture, transportation and injection, and, furthermore, the importance of appropriate monitoring programmes and approaches related to remediation if emissions should occur.

23. It is recommended that any CCS project activities approved under the CDM should employ proper risk management and operation and monitoring of reservoirs and should feature appropriate remediation programmes to be employed in the event seepage should occur. For any proposed CCS CDM project activities all these aspects should be fully described. Seepage remediation options should be described in connection with an analysis of the most likely seepage scenarios in implementing any methodologies.

24. The validation of the remediation plan would require a DOE with appropriate CCS expertise.

[5] FCCC/SBSTA/2008/INF.1, Synthesis on views on issues relevant to the consideration of carbon dioxide capture and storage in geological formations as clean development mechanism project activities.
[6] FCCC/SBSTA/2008/INF.3, Synthesis on views on technological, methodological, legal, policy and financial issues relevant to the consideration of carbon dioxide capture and storage in geological formations as project activities under the clean development mechanism.

Methodological Issues

Monitoring and Verification

25. The 2006 IPCC Guidelines provide an overarching framework for monitoring and verification of CO_2 storage in geological formations in terms of GHG mitigation performance. The methodology provided by the IPCC (a Tier 3 methodology based on site characterisation, modelling and monitoring) states that zero seepage can be assumed for appropriately selected and managed sites if the evidence from modelling and monitoring indicates so. This methodology for monitoring and verification could also be applied to CCS project activities under the CDM.

26. The 2006 IPCC Guidelines are non-prescriptive on monitoring techniques because it is recognised that every storage site is geologically different and that different monitoring techniques have different applicability for different geological situations. This means that the monitoring programme and techniques selected for any CCS project activities under the CDM should be determined by the ex ante site characterisation and modelling of the CO_2 behaviour and will therefore be site specific. Leaving flexibility in the monitoring programme details, whilst setting the overall objectives, ensures integrity while allowing the most appropriate monitoring techniques to be selected for each site. This principle of flexibility is also demonstrated in recent legislation for CCS such as the London Protocol, OSPAR, the EU Directive on geological storage of carbon dioxide, the US EPA Draft Rule, and the Australian Commonwealth and State legislation.

27. According to the 2006 IPCC Guidelines additional monitoring is required to quantify seepage amounts should seepage be detected. An important requirement for monitoring programmes is that the monitoring results during project operation are used to check against the ex ante modelling of CO_2 behaviour, and the modelling improved ex post if necessary, the results of which may then suggest modifications to the monitoring programme.

28. New Monitoring Methodologies would need to be created for any CCS project activities under the CDM, and it is recommended that all CCS Monitoring Methodologies should follow the same four objectives of performance monitoring, seepage detection, seepage quantification and seepage impact assessment, with the latter two objectives only being triggered if leakage is detected or suspected from the monitoring results of the first two objectives.

29. Monitoring Methodologies should set overall objectives while leaving flexibility in the monitoring programme details, so as to allow the most appropriate monitoring techniques to be selected given specific geological situations. The First UNFCCC Synthesis Report provides a listing of the elements to be included in a monitoring programme, derived from the IPCC GHG Guidelines. It is recommended that these should be followed in any CCS CDM Monitoring Methodologies. For each project, the monitoring programme and techniques should be derived from the site characterisation and modelling for the particular site, and fully described in the PDD so that they can be assessed. Within the context of the subsurface element of a CCS CDM methodology/ies there should be a periodic requirement for the revised modelling results to be re-assessed by a DOE.

30. In addition to this storage-related monitoring there will be monitoring of emissions related to the surface-related project activity, ie the combustion or process emissions, transport, etc, as would be expected with other CDM projects.

31. The assessment of a monitoring programme (in the PDD) would require a DOE with appropriate CCS expertise. It is recommended that DOEs wishing to validate CCS projects would have to be accredited with this expertise, which would require a new sectoral scope to be introduced in the CDM. Thorough understanding of the permanence issue requires advanced expertise in complex technical areas.

32. It is recommended that, if CCS is considered eligible under the CDM, the Board establishes a CCS Working Group. The Working Group shall have the mandate to support the Board on technical issues related to the permanence of CO_2 storage in geological formations, including the accreditation of DOEs to validate CCS projects, supporting the Board in developing criteria for the assessment of CO_2 storage site selection and approval, and preparing recommendations on technical matters related to the permanence of CO_2 storage in submitted proposals for new baseline and monitoring methodologies. The establishment of an expert group to support Board work related to CCS was supported by Parties in their submissions (First and Second Synthesis Reports).

33. If seepage from geological storage should occur, it would raise an issue concerning uncertainty about the accuracy of quantification of seepage amounts. An example of how to apply a conservative principle is provided by the EU ETS Monitoring and Reporting Guidelines for CCS. In these, if the uncertainty is above a specified level for the measured emissions of seepage, these measured emissions will be multiplied by an 'uncertainty supplement'. For CO_2 storage site seepage, it is recommended that any uncertainty in quantification needs to be addressed to avoid underestimating actual seepage emissions. It is recommended that any new Monitoring Methodologies for CCS in the CDM should use the same factors as in the EU regulation so as to avoid underestimating seepage amounts.

34. Also, in temporal terms, to avoid underestimating the seepage amounts, the EU ETS Monitoring and Reporting Guidelines proposes that seepage is assumed to have occurred over time dating back to when evidence shows there wasn't a seepage event or by default back to the date on injection, unless other evidence indicates otherwise.

35. To safeguard the environmental integrity of any CCS project activities under the CDM, monitoring of storage sites should continue after site closure and the end of the CDM crediting period, although this monitoring can be reduced if evidence indicates the CO_2 is "approaching its predicted long-term distribution" with no suggestion of potential seepage (as stated in the IPCC GHG Guidelines, and also in the EU Directive). It is recommended that the Board considers requirements for monitoring post closure and post CDM crediting period for any proposed geological CCS CDM methodologies regardless of whether the storage site is in the responsibility of the operator or if the responsibility has been transferred to a state authority.

Regulatory Requirements

36. Best practice suggests that regulatory control of any CCS project will be needed in order to ensure appropriate protection of human health and the environment. Several examples now exist of such regulatory control for CCS from different countries, all similar in their principles and requirements (e.g. Australia, USA, Japan, EU). Regulatory best practice now shows that permit applications should include a risk assessment (including the site characterisation and modelling), monitoring plans, remediation plans (in the event of seepage), and closure plans.

37. It is recommended that regulation of CCS in the host country, with an appropriate regulatory body to administer it, is highly important for CCS CDM projects. It is recognised that it may take time

and resources for a host country to develop regulation to the degree and detail that exists in the examples mentioned and support to facilitate such developments may be considered. An objective of any DOE validating a CCS CDM project activity would be to assess whether there is a regulatory framework that could be considered sufficient in place in the host country to control the project, and whether the appropriate regulatory approval has been or can be given to the particular project.

Other Methodological Issues - Project Boundaries

38. In terms of spatial boundaries, the First Synthesis Report indicates that there is clarity amongst Parties on all the aspects of a CCS project which should be included within the project spatial boundary, i.e. all aspects from capture, transport and storage.

39. Thus, the project boundary should comprise both above ground and below ground components, including a larger volume than just the storage reservoir so as to include potential secondary containment formations. This larger volume, referred to as a 'storage complex', being the storage site and surrounding geological domains which can have an effect on overall storage integrity and security. Using a good site characterisation and modelling, together with inclusion within the boundary of a storage complex, could be considered sufficient for projects to be able to proceed in the CDM. In the event that CO_2 does move out of the project spatial boundary, the PDD should be revised and reassessed by the DOE and the Board, with the option of changing the spatial boundary as the most important thing is to ensure all potential seepage locations are included within the project boundary.

40. In terms of project temporal boundary, this should recognise that there is the potential for seepage after the CDM crediting period and after project closure until evidence indicates that the CO_2 plume is stabilising at its long term distribution, and even potentially after liability transfer to a host country.

41. The project temporal boundary should include all of the above up to the end of a monitoring period undertaken by a responsible entity after liability transfer. Monitoring activities carried out by the host country could be reported in its National Communications to the UNFCCC, following IPCC Guidelines applicable at the time.

Legal Issues

Risks and Liabilities - Potential CO_2 Seepage

42. The potential for long-term seepage of CO_2 from geological CO_2 storage will outlast the CDM project crediting period. This risk of seepage, even if extremely small for appropriately selected and managed storage sites, would still have to be addressed to assure of the environmental integrity of the CDM if CCS were made eligible as CDM project activities.

43. Guiding principles proposed by Parties in submissions and highlighted in the Second Synthesis Report include that accounting rules should be consistent with current rules under the CDM, and CERs should be as permanent and fungible as those from other project activities.

44. <u>During the crediting period of a CCS project under the CDM, the liability for CO_2 seepage should reside with the operator.</u> <u>The 2006 IPCC Guidelines established the principle that CO_2 transferred to a CO_2 storage site counts as not emitted, which is followed by the revised EU ETS Directive. In the EU ETS system, if there are subsequent seepage emissions from storage, then the storage operator has to surrender emission allowances equivalent to the seepage amount. It is recommended that this principle be applied for CCS CDM projects also, in the short and long-term.</u>

45. Any seepage amounts should be treated as project emissions. Potentially, this could mean that the operator would have to purchase CERs on the market to surrender appropriate amounts if the seepage amounts exceed the net storage amounts for one monitoring/verification period.

46. After<u> the CDM project crediting period, there would have to be a means of ensuring the environmental integrity of the CDM is maintained in the event of seepage. The basic requirement should be that CERs (or equivalent at the time) equal to the quantity of seepage CO_2 should be surrendered by an entity responsible for the project to the UNFCCC CDM Registry Account, and the seepage source would be remediated.</u>

47. There is a widely held view by many Parties that the ultimate liability should be with the host country, as they have ultimate responsibility in terms of regulatory approval, site ownership and jurisdiction over the site. However, the risk can be reduced or removed from host countries with the use of instruments such as long-term financial bonds or insurance or contractual arrangements with the project operator.

48. <u>Given the range of options open, and the limited number of projects expected in developing countries during the first and a second commitment period, it is suggested that at this early stage, if CCS were allowed in the CDM and assuming long-term liability transfer to the host country, host countries should be allowed to choose their liability transfer and funding mechanisms, so as to allow 'learning'. It is recommended that the DOE and the Board would need to be satisfied with the outline arrangements to undertake liability transfer, which should be detailed in advance in the post-closure plan in the PDD, and to give their approval or not.</u>

49. Liability for safety and environmental damage should be dealt with through appropriate national regulations, although compensation arrangements can be included in the project design.

International Boundary Issues

50. Concern over the legal implications of storage and seepage which cross national boundaries and in international waters was raised by several Parties in the Synthesis Reports.

51. Due to the additional legal implications for cross-border storage it is suggested that CCS projects in the first and a second commitment period would be limited to take place within national boundaries and with no risk of migration across national boundaries.

52. This suggestion is also supported by some Parties in The First and Second Synthesis Reports.

Environmental Implications

Impurities in CO_2 streams

53. The presence of impurities in CO_2 streams has implications for the environmental performance of CCS. Parties in their submissions, as reflected in the UNFCCC Synthesis Reports, suggest that no waste or other matter should be added to a stream for the purpose of discarding that waste or other matter. However, it was argued that CO_2 streams for injection may contain incidental associated substances derived from the source material and the capture, transport and storage processes used. Parties also state that that the acceptable concentration of any substance should depend on its potential impact on the integrity of the storage site, relevant transport infrastructure, and the risk to the environment considering the applicable regulations. It is worth noting that these overall recommendations are in line with recent amendments to the London Convention and OSPAR as well as with EU Directive on geological storage of carbon dioxide. The principle of these regulations is that CO_2 streams for geological storage shall consist "overwhelmingly of carbon dioxide".

54. If CCS is considered eligible under the CDM it is recommended that no waste or other matter may be added to a CO_2 stream of a CCS CDM project activity for the purpose of discarding that waste or other matter and that acceptable levels of impurities in CO_2 streams be determined based on its potential impacts on transport and storage integrity. It is furthermore recommended that operators of potential CCS projects under the CDM prove that their CO_2 streams are sufficiently pure and that they have adequately considered the relationship between CO_2 stream purity and the surrounding cap rock, including environmental and other risks of CO_2 storage.

Environmental Impact Assessment

55. There was broad agreement across Parties and organizations that any methodology applicable to CCS as a CDM project activity would need to incorporate a thorough risk assessment of the storage site and operation which shall include an assessment of all potential seepage paths and environmental impacts, using detailed site characterization and simulation techniques.

56. It is recommended that the Environmental Impact Assessment carried out for each potential CCS project under the CDM, albeit governed by national regulations, should be based on the risk assessment procedure that should be outlined in any CCS CDM methodology and PDD.

Uptake of CCS and Market Implications

57. CCS leads to an increase in capital and operating expenses, combined with a decrease in plant energy efficiency. Costs of CCS vary depending on a range of technical factors. In most cases CO_2 capture dominates the cost of CCS. However, in certain cases the cost of CO_2 separation is avoided as it an integral part of the process(e.g. in certain natural gas processing situations and in ammonia production) – in these cases, when the baseline means venting the CO_2 into the atmosphere, additional cost are incurred for CO_2 treatment (e.g. dehydration), compression, transport and storage. In certain cases CCS activities may also have some economic benefits beyond climate change mitigation, e.g. Enhanced Oil Recovery (EOR) activities or decreased local air pollution. The relative costs or benefits of different types of CCS activities will affect their likelihood of being undertaken in a business-as-usual scenario, and thus their additionality under the CDM.

58. Commercial CCS projects in the power sector will only be realistic on the longer-term where a CO_2 price signal, or direct regulation/mandates for CCS occur. According to the most recent estimates, and in terms of cost per tonne of CO_2 avoided[7], near-term costs for CO_2 capture and storage for coal-fired power plants are quite high, dropping to USD 50-65 in 2030. For gas-fired power plants costs are generally higher, predicted to drop to USD 55-90 in 2030. Therefore, it is necessary to look beyond the power sector to identify near-term opportunities for CCS.

59. Analyses concerning the technical potential for near-term CCS deployment in non-Annex I countries generally suggest a limited short term potential which is found in non-power sector applications (e.g. in ammonia plants, some fuel transformation processes (for example, ethanol and hydrogen), and natural gas processing), although longer term potential is high, subject to cost reductions and incentives for deployment being in place.

60. Analyses have been made specifically addressing the potential for CCS as CDM project activities taking into account, inter alia, existing and predicted CO_2 sources where CCS could be applied and the associated CCS costs, CER price levels, and lead times for project implementation. This analysis concluded that the CCS share of CER supply would be very low before 2012 at current estimates of CER supply and demand, were CCS considered eligible under the CDM. For 2020, results indicate that the potential CCS share of the CER market would be below 10 per cent of total supply. CCS might improve its cost-competitiveness beyond 2020 assuming elevated CER price levels and reduced CCS costs in the power sector and some industrial sectors, however uncertainties are significant and quantifications are not available. It can be concluded that, due to barriers for CCS implementation, there are no indications that CCS being made eligible under the CDM would introduce any risk of unbalancing the carbon market.

61. With respect to regional issues, it can be concluded that a vast share of the near-term potential for CO_2 capture can be found in oil- and gas-producing regions. The economics will be particularly favourable when and where there are opportunities for EOR. However, with some exceptions regions with vast potentials for CO_2-EOR are generally not close to large CO_2 emission nodes. Studies indicate that if CCS is made eligible under the CDM it may enhance regional distribution. This potential will also be subject as to whether EOR would also be eligible in the CDM, as this presents additional methodological and leakage issues compared to pure CO_2 storage projects (e.g. accounting for CO_2

[7] Thus taking into account the impact of efficiency losses etc, as opposed to the “cost of CO_2 captured”.

"breakthrough" with produced oil, and the downstream emission from the combustion of incrementally produced oil)

62. It can furthermore be concluded that a large share of the estimated long-term technical potential for CO_2 capture is associated with emissions from the power sector, with the implication that coal-based economies represent a significant share of the long-term potential for CCS under the CDM or other future emissions trading mechanisms. Application of CCS to the large future emissions of the power sector in fossil-fuel, and particularly coal-based, developing economies will also be important to avoid dangerous levels of climate change occurring.

Other Funding and Technology Transfer Alternatives for CCS

63. Given the large sums of money that will be needed to adequately demonstrate CCS, the climate change benefits, and the need for the international transfer of knowledge and technology, governments and international financial institutions have an important role to play in financing CCS, in particular at the early stages of technology demonstration and commercialisation. A number of initiatives to facilitate international transfer of knowledge and technology related to CCS have been taken by the Asian Development Bank, the World Bank, the EU, and the European Investment Bank. Initiatives such as these will be particularly important for the demonstration of CCS in the power sector in developing countries as financial incentives from market-based mechanisms alone will be insufficient in the near to medium term to stimulate CCS investments in this sector.

C. Technical Issues

64. Carbon dioxide capture and storage is a three-stage process consisting of the capture of carbon dioxide (CO_2), the transportation of CO_2 to a storage location, and the long-term isolation of CO_2 from the atmosphere.

65. Due to reasons related to economies of scale, CCS systems are most likely to occur in connection with large point emission sources. Within the limits of this restriction, CCS may be applied to mitigate CO_2 emissions from a range of point sources, each with specific characteristics. Furthermore, there is a number of competing technologies at various stages of development and commercialisation within each stage of the process (capture, transport and storage). Table 1 provides an illustration of the range of components that can be combined in a complete geological CCS system as well as the variability in the current maturity of the system components. With multiple options for each stage that can be combined into an integrated system, the maturity of CCS technology is a complex issue. However, for all stages involved there are technologies that work well today for certain applications. The IPCC Special Report on Carbon Dioxide Capture and Storage ("IPCC SR") has concluded that complete CCS systems can be assembled from existing technologies that are mature or economically feasible under specific conditions[8]. The first few commercial CCS projects are in operation[9].

66. The remaining part of this section covers, in some more detail, how and where CO_2 capture might take place, CO_2 transportation, geological CO_2 storage and issues related to permanence of storage and its long-term integrity, and possible sources of emissions from geological CCS and the uptake of CCS technology as a carbon abatement option.

---

[8] IPCC Special Report on Carbon Dioxide Capture and Storage (2005), Summary for Policymakers, p. 8.

[9] IEA. CO2 Capture and Storage – A key carbon abatement option. Paris, 2008.

Table 1. Current maturity of system components for geological CCS. The X's indicate the highest level of maturity for each component. For most components, less mature technologies also exist (Based on IPCC Special Report on Carbon Dioxide Capture and Storage (2005). Technical Summary, Table TS1).

CCS component	**CCS technology**	**Demonstration phase**	**Economically feasible under**	**Mature market**
Capture	Post-combustion		X	
	Pre-combustion		X	
	Oxyfuel combustion	X		
	Industrial separation (natural gas processing, ammonia production)			X
Transportation	Pipeline			X
	Shipping		X	
Geological storage	Saline formations		X	
	Gas or oil fields		X	
	Enhanced Oil Recovery (EOR)			X
	Enhanced Coal Bed Methane recovery	X		

a CO_2 injection for EOR is a mature market technology, but when this technology is used for CO_2 storage, it is only 'economically feasible under specific conditions'

Capture Issues and CO_2 Sources

67. CO_2 capture involves the separation of CO_2 from mixtures of gases and its compression and dehydration into a supercritical fluid state for transport and storage. CO_2 separation technology is applied widely today as an inherent part of production processes in, for example, some chemical industries and natural gas processing albeit in most cases vented to the atmosphere. CO_2 separation involving the use of liquid solvents has been in operation for over 50 years, with 100's of plants currently operating worldwide in the natural gas and chemicals industry. Companies such as BASF, Linde, Four Daniel, Air Liquide, and MHI are commercial vendors of such equipment. Application of these technologies for the separation of CO_2 from flue gas mixtures exiting combustion processes has not been widely applied, and has not been proven at the scale and composition of gases applicable for large power plants.

68. However, CO_2 capture (separation, compression and dehydration of CO_2) and subsequent transportation over shorter or longer distances have been commercially applied for several decades to generate CO_2 streams for various uses. In addition, the first large-scale CO_2 capture projects with subsequent transportation and storage for the sole purpose of climate change mitigation have been taken into operation since mid-1990. These activities occur primarily for emission sources where

(a) CO_2 is available at high concentration and pressure, i.e. conditions under which the CO_2 can be more readily captured, or

(b) There is a second and valuable output from the process, such as natural gas, and the production thereof necessitates CO_2 separation.

Processes for CO_2 Capture

69. The relevant processes for CO_2 capture include:

"Post-combustion capture": CO_2 is separated from the flue gases after combustion of the fuel. Post-combustion capture can be used to separate CO_2 from the flue gases of facilities such as power plants and industries. This technology uses liquid solvents to dissolve the CO_2, which is then released for compression at a later stage in the process.

"Pre-combustion capture": CO_2 is separated from a hydrocarbon feedstock before the fuel is combusted or further processed. For this technology, the feedstock is converted to hydrogen and CO_2 through a number of chemical processes. For solid feedstock, such as coal or biomass, it is initially gasified. When the CO_2 has been separated the remaining hydrogen can be used for combustion or for another purpose. The separation technology used for pre-combustion capture involves liquid solvents and has similarities with post-combustion capture. However, due to reasons related to CO_2 concentration and CO_2 partial pressure of the stream from which CO_2 is separated, pre-combustion capture technology offers the benefit of cost reductions and efficiency improvements compared to post-combustion separation of CO_2 from flue gases.

"Oxy-fuel capture": In this process, the fuel combustion takes place in an oxygen-rich environment. When fuel is combusted in air, CO_2 concentrations are relatively low since air consists mostly of nitrogen. For the oxy-fuel process, nearly pure oxygen is used for combustion instead of air, resulting in a flue gas that is mainly CO_2 and water vapour. Higher concentrations of CO_2 are expected to make separation less expensive. A major challenge is that it is expensive and demands energy to produce pure oxygen. This technology differs significantly from the above two in that the separation of CO_2 is not based on the use of solvent.

70. On the long-term there will probably be new alternatives for CO_2 capture that are more efficient and cost-effective for certain applications. Some of those alternatives, still in the research phase, are membrane-based technologies, adsorption and chemical looping combustion.

71. It is important to note that the captured CO_2 stream may contain impurities, the types and concentration of which depend on the type of capture process applied and detailed plant design. If substances are captured along with the CO_2 then emissions to the atmosphere will be reduced, but impurities in the CO_2 would have practical impacts on CO_2 transport and storage systems and also potential health, safety and environmental impacts. Those implications are addressed in relevant sections of the report. CO_2 from post-combustion processes normally contains low concentrations of impurities. Many of the existing post-combustion capture plants produce high purity CO_2 for use in the food industry. CO_2 from pre-combustion solvent-based processes typically contains about 1-2% H_2 and CO and traces of H_2S and other sulphur compounds. CO_2 from oxy-fuel processes contains oxygen, nitrogen, argon, sulphur and nitrogen oxides and various other trace impurities. This gas will normally be compressed and fed to a purification process to reduce the impurities concentrations to the levels required for pipeline transportation.

CO_2 Capture in Relation to Sources of CO_2

72. The possibility of CO_2 capture in power and heat plants deserves special attention due to the abundant CO_2 emissions in this sector world-wide. Post-combustion capture is the alternative that could most easily be retro-fitted to existing facilities, as this option requires less integration with the main process compared to the other two. Post-combustion capture is used today on a small scale in some power plants (typically capturing CO_2 from only part of the flue gases) either to produce CO_2 for industrial uses or in test facilities for CCS. Compared to the currently more wide-spread commercial use of the technology in industrial processes, challenges ahead for applications in heat and power plants include lower CO_2 concentrations and significantly larger scales. Integration is particularly challenging for pre-combustion CO_2 capture in power plants, in the design as well as operation. Pre-combustion capture of CO_2 from gasification-based processes is not a major challenge – several commercial processes are available. The major obstacle, however, lies in reducing the cost of building and operating an entire power plant with the integrated advanced chemical process systems involved in pre-combustion capture to make it commercially feasible for the power industry. E.g., power plants with integrated gasification require advanced and complex design and, moreover, designing plants which are able to operate on the hydrogen-rich fuel that comes out of the pre-combustion capture process adds further engineering challenges. The oxyfuel process is the least developed of the three major options for CO_2 capture for power production. Several small research and demonstration facilities are in operation and methods to overcome technical challenges are being explored.

73. Outside the power and heat sector there are abundant CO_2 emissions in the industrial sector that could potentially be addressed with CCS. In the industrial sector, several types of facilities feature chemical reactions that lead to the formation of CO_2 in quantities and concentrations that allow feasible capture of the CO_2. CO_2 is separated commercially today from natural gas processing streams and in industries where ammonia or hydrogen production is part of the main process. In these cases, CO_2 is separated as an inherent part of the production process and not primarily to generate a CO_2 stream. The additional cost of CO_2 capture and storage is therefore limited to compression, transportation and storage in these applications and is thus lower compared to cases where CO_2 separation is implemented solely for the purpose of reducing emissions. Examples of industrial production processes that do not already involve CO_2 separation but where CO_2 capture is being explored include cement manufacture, pulp and paper production, ethanol manufacture, oil refining, and iron and steel manufacture. In each case there are industry-specific challenges, such as the presence of impurities in the gas mixtures from which CO_2 might be captured, and capture methods need to be tailored to the specifics of the industrial process environment. Adaptations of post-combustion, pre-combustion, and the oxyfuel process have been explored for various types of industrial processes. Capture of CO_2 from these industries will require integration with the production processes and in many cases require modifications to long-established practices.

74. It is not clear today which technology candidates will come out as the most competitive in the end and ultimately different approaches are likely to prove most competitive under different circumstances.

CO_2 Transport

75. There will be a need for CO_2 transportation for the implementation of CCS as the capture of CO_2 cannot always be placed immediately above a storage site. CO_2 can be transported as a gas in pipelines and ships and as a liquid in pipelines, ships and road tankers.

76. Transporting supercritical CO_2 in pipelines is an established technology[10]. Globally, approximately 5 600 km of long-distance CO_2 pipelines annually handle over 50 million tonnes CO_2 from anthropogenic and natural sources[11]. The oldest CO_2 pipeline was established in 1972 in the United States. It transports approximately 5 million tonnes CO_2 per year from natural (i.e. mined) and anthropogenic sources of CO_2 (the latter includes natural gas processing plants and ammonia plants). The largest individual transportation network in the United States has a capacity to annually transport over 30 million tonnes CO_2 over 800 kilometres. Risks associated with CO_2 transport have been documented by the IPCC SR[12]. CO_2 presents no explosion- or fire-related risks but can accumulate in low-lying areas where it can create a health risk or even be fatal at high concentrations. The presence of impurities in the CO_2 can raise the risk of fugitive emissions from transportation. Monitoring, the development of technical standards and careful route selection are examples of approaches that can mitigate risks related to fugitive emissions. It can be noted that up to 2006, CO_2 pipeline transportation shows a lower rate of seepage per kilometre of pipeline than natural gas pipelines.

77. In some cases transport of CO_2 by ship may be economically more attractive compared to pipeline transport, particularly when the CO_2 has to be moved over large distances or overseas. Liquefied petroleum gases (LPG, principally propane and butane) are transported on a large commercial scale by marine tankers and CO_2 can be transported by ship in much the same way, albeit with a need to modify the process slightly. Transportation by ship would add flexibility with respect to where CO_2 is collected by the source and where CO_2 from a particular source is delivered for storage.

78. In the end, the selection of CO_2 transportation method would be made on a case-by-case basis, taking both the relative economics of alternatives and practical considerations into account.

CO_2 Storage

79. Geological CO_2 storage is accomplished by injecting captured and transported CO_2 in a dense form into the porous spaces of suitable deep rock formations. It can be undertaken in a variety of geological settings where sedimentary basins exist - onshore or offshore. Oil and gas reservoirs, deep saline formations and deep, unmineable coal beds represent promising opportunities for geological CO_2 storage. CO_2 storage in oil and gas reservoirs can take place in depleted reservoirs or in partially depleted reservoirs for so-called enhanced hydrocarbon recovery (EHR).

80. Many of the technologies required for large-scale geological storage of CO_2 already exist. The IPCC SR notes that the injection of CO_2 in deep geological formations involves many of the same technologies that have been developed in the oil and gas exploration and production industry[13]. Well-drilling technology, injection technology, computer simulation of storage reservoir dynamics and monitoring methods from existing applications are being developed further for design and operation of geological storage. Other underground injection practices also provide relevant operational experience, for example, natural gas storage, the deep injection of liquid wastes, and acid gas disposal. The established technologies are being practiced with some adaptations in current CO_2 storage projects.

[10] IPCC Special Report on Carbon Dioxide Capture and Storage (2005), Chapter 4, pp 182-184.
[11] IEA. CO2 Capture and Storage – A key carbon abatement option. Paris, 2008.
[12] IPCC Special Report on Carbon Capture and Storage (2005), Chapter 4, pp. 187-189.
[13] IPCC Special Report on Carbon Capture and Storage (2005), Chapter 5, pp. 230-231.

81. Relevant options for CO_2 storage in geological formations include[14 15]:

CO_2 storage in depleted oil and gas fields characterised by readily available extensive geological and hydraulic assessments from the oil and gas operations, the presence of sealing mechanisms that would be expected to contain gaseous systems for extended periods of time (the oil and gas that originally accumulated did not escape - in some cases for many millions of years - demonstrating their integrity and safety), and an existing infrastructure for CO_2 injection.

82. If hydrocarbon fields are still in production, a CO_2 storage scheme can be optimized to enhance oil or gas production, known as Enhanced Oil Recovery, EOR and Enhanced Gas Recovery, EGR, respectively. For more than 30 years, oil producers have injected CO_2 to enhance oil recovery in wells. Once underground injection of CO_2 is finished, the injection well can be capped and the CO_2 stored underground. The increase in oil production would help in offsetting the costs of CCS. CO_2 EOR is limited to oilfields deeper than 600 metres where a minimum of 20% to 30% of the original oil is still in place. These and additional restrictions limit the potential of EOR. Enhanced Gas Recovery, on the other hand, ahs so far only been implemented at pilot scale and would require significant demonstration efforts before the technology becomes established. In EGR, CO_2 would be injected to repressurise depleted gas fields to increase gas recovery, generally after more than 80% of the original gas has been produced. The economics of CO_2 EGR are less favourable than CO_2 EOR, as the revenue per tonne of CO_2 injected is lower.

83. CO_2 storage can also take place in deep saline aquifers. Aquifers are layers of sedimentary rocks that are saturated with water that can either be open or confined. Many aquifers, particularly those in sandstone and carbonate rocks, are permeable enough for fluids to be injected. Other types of rock, such as granite, do not have the porosity and permeability necessary for CO_2 storage, and they are usually fractured in a way that may create potential leakage pathways. CO_2 injected into deep saline aquifers is trapped through a number of mechanisms (see the section on Permanence of CO_2 storage).

84. Deep coal beds may be used for storage of CO_2 provided that it is unlikely that the coal will later be mined. Unmineable coal seams are those that are either too deep or too thin to warrant commercial exploitation. Coal can physically adsorb many gases and has a higher affinity to adsorb gaseous CO_2 than methane. Gaseous CO_2 injected through wells will be adsorbed onto the coal micropore surfaces, freeing up gases with lower affinity to coal (i.e., methane). The injection of CO_2 into deep unmineable coal seams can therefore be used both to enhance the production of coal bed methane and to store CO_2. However, the option is still in the demonstration phase.

Permanence of CO_2 Storage

85. Geological formations in the subsurface are composed of rock grains, organic material, and minerals that form after the rocks are deposited. The pore space between grains or minerals, as well as open fractures and cavities, are occupied by fluid (mostly water). Once the CO_2 is injected into a storage formation the CO_2 can diffuse through the pore spaces of the rock formation and become trapped.

86. CO_2 storage in oil and gas reservoirs or deep saline formations is generally expected to take place at depths below 800 metres, where the ambient pressures and temperatures will result in CO_2 being in a

[14] IPCC Special Report on Carbon Capture and Storage (2005), Chapter 5.
[15] IEA. CO2 Capture and Storage – A key carbon abatement option. Paris, 2008.

supercritical state. Supercritical CO_2 will take up as little as 0.3 percent of the space that gaseous CO_2 takes up at atmospheric conditions, thereby providing for efficient utilization of underground storage potential. Under these conditions, the density of CO_2 will range from 50 to 80 percent of the density of water, resulting in buoyant forces that tend to drive CO_2 upwards. Injecting CO_2 in a supercritical state, as compared to in a gaseous state, will thus limit buoyancy and thereby improve storage security. The presence of a sealing layer (i.e. a caprock formation) is of primary importance as described below.

87. In an appropriate geologic storage formation, CO_2 is held in place by one or more of several trapping mechanisms, depending on geology and time[16], see Figure 1.

- "Structural" and "stratigraphical" trapping occurs where the migration of free CO_2 in response to its buoyancy and/or pressure gradients within the formation is prevented by low permeability barriers (caprocks). In the case of stratigraphical trapping, a dense layer of impermeable rock overlies the CO_2 deposit forming a closed container. The changes in rock type between the CO_2 deposit and the low permeability barrier is caused by variation in the setting where the rocks were deposited. Structural traps include those where impermeable rocks overlie a fault or fold in the geologic strata, thus holding the CO_2 in place.

- "Residual saturation trapping" occurs when capillary forces, trapping $C0_2$ in the tiny pores between rocks, and adsorption onto the surfaces of mineral grains within the rock matrix immobilise a proportion of the injected CO_2 along its migration path.

- "Solubility trapping" occurs when CO_2 dissolves in the saline water in the rock formation. Once this occurs (over time scales of tens of thousands of years), the CO_2 no longer exists as a separate phase, thereby eliminating the buoyant forces that drive it upwards. The CO_2-laden water becomes more dense than the surrounding water and therefore sinks down into the formation, thus minimizing the risk for long-term seepage.

- Geochemical trapping occurs when dissolved CO_2 combines chemically with the native pore fluid of the formation and/or the minerals making up the surrounding rocks. CO_2 is incorporated into the reaction products as solid carbonate minerals ("mineral trapping") and aqueous complexes dissolved in the formation water.

- Yet another type of trapping occurs for storage in deep coal beds[17] when CO_2 is preferentially adsorbed onto coal or organic-rich shales replacing gases such as methane. In these cases, CO_2 will remain trapped as long as there are stable pressures and temperatures.

88. These types of trapping mechanisms have retained buoyant gases in geological formations for millions of years, as evidenced by the presences of ancient gas deposits around the world.

[16] IPCC Special Report on Carbon Capture and Storage (2005), Chapter 5, pp. 208-210.

[17] CO2 storage is generally considered for unmineable coal beds. The use of mineable coal beds for CO2 storage could lead to subsequent conflicts of interest. However, the trapping mechanism would occur for deep coal beds regardless of their suitability for mining.

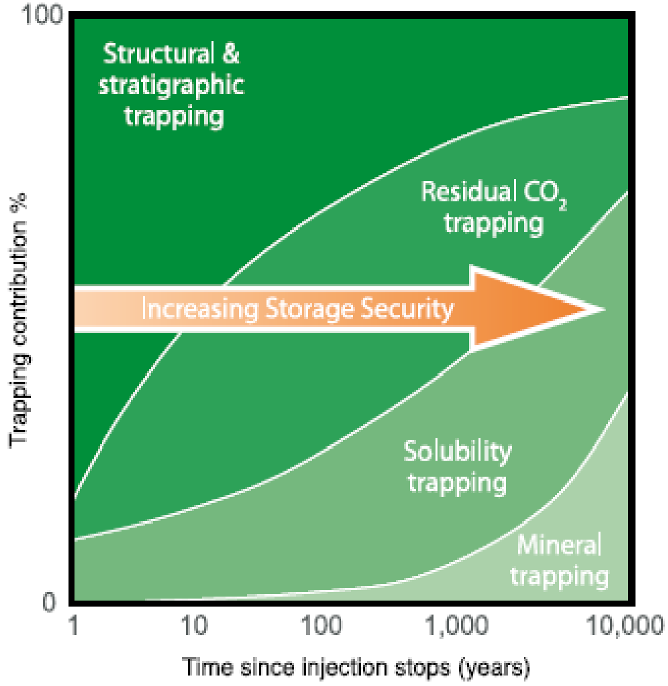


Figure 1: Trapping mechanisms in geological storage over time (Source: IPCC Special Report on Carbon Dioxide Capture and Storage (2005), Chapter 5, Figure 5.9.

89. The IPCC SR has assessed minimum expected CO_2 retention levels for appropriately selected and managed formations and concludes[18], based on observations and analysis of current CO_2 storage sites, natural systems, engineering systems and models, that the fraction retained is very likely to exceed 99% over 100 years, and is likely to exceed 99% over 1000 years. The IPCC SR furthermore concludes that similar fractions retained are likely for even longer periods of time, as the risk of seepage is expected to decrease over time due to the activation of more stable forms of CO_2 trapping (Figure 1). According to the IPCC SR, storage could become more secure over longer time due to these trapping mechanisms and CO_2 could be retained for up to millions of years.[19]

90. With respect to experience from existing research and demonstration projects, observations from monitoring activities are accumulating. In the Weyburn-Midale project (Canada) approximately 2.8 million tonnes CO_2 per year are injected into partially depleted oil fields. The injected CO_2 has been monitored since injection started in 2000 and the project has performed largely as predicted with no indication of CO_2 seepage to the surface and near-surface environment[20]. The Sleipner project in the North Sea about 250 km off the coast of Norway, is the first commercial-scale project dedicated to geological CO_2 storage in a saline formation for the purpose of climate change mitigation. The formation has been monitored since 1994 and injection of around 1 million tonnes CO_2 annually started in 1996.

[18] IPCC Special Report on Carbon Capture and Storage (2005). Chapter 5, p. 246.
[19] IPCC Special Report on Carbon Capture and Storage (2005), Summary for Policymakers, p. 14.
[20] IPCC Special Report on Carbon Capture and Storage (2005), Chapter 5, p. 204.

The monitoring has been successful and shows that the caprock (structural and stratigraphic trapping) is an effective seal that prevents CO_2 migration out of the storage formation[21] [22]. Experiences from three years of monitoring of solubility trapping have been built in the Nagaoka project (Japan)[23].

CO_2 Storage Site Characterisation and Selection

91. Addressing risks and preventing the long-term seepage for CO_2 storage in geological formations are key issues to ensuring the integrity of geological CCS as a GHG mitigation option. The characteristics of geological formations differ and their suitability for long-term CO_2 storage depends strongly on their individual properties. Therefore, detailed site characterisation, including assessing site-specific risks of potential long-term seepage, is a requirement for appropriate site selection[24]. Generally, methods for site characterisation are well established. Techniques developed for the exploration of oil and gas reservoirs, natural gas storage sites and liquid waste disposal sites are suitable for characterizing geological storage sites for CO_2[25]. Assessments necessary for characterisation and selection of sites include determination of local geology, hydrogeology, geochemistry, and geomechanics supported by detailed behaviour modelling and simulation using the real data from the site characterisation.

92. Any CCS project activities approved under the CDM should be located to secure sites and operated according to best practice. Those projects should employ an appropriate site selection process, proper risk management, operation and monitoring of reservoirs and should feature appropriate remediation programmes in the event that seepage should occur.

93. The IPCC SR provides a general framework for the storage site characterisation and selection process and the 2006 IPCC Guidelines for National Greenhouse Gas Inventories (“2006 IPCC Guidelines”) provide an approach, based on detailed site characterisation and modelling and simulation, to the selection of storage sites. The approach used by the London Convention[26] and OSPAR Convention[27] in their risk assessment and management guidance for CO_2 storage. More recently, also drawing on the IPCC SR and the 2006 IPCC Guidelines, the European Union has established a legal framework for geological CO_2 storage[28] including detailed “criteria for the characterisation and assessment of the potential storage complex and surrounding area”.

[21] IPCC Special Report on Carbon Capture and Storage (2005), Chapter 5, p. 202.

[22] Chadwick, A. et al. (2006). Geophysical monitoring of the CO2 plume at Sleipner, North Sea. In: Lombardi, S. et al (ed.) Advances in the Geological Storage of Carbon Dioxide Advances in the Geological Storage of Carbon Dioxide. Springer, Netherlands.

[23] Miti, S (2009). Post-Injection Monitoring to Ensure Safety of CO2 Storage - A case study at Nagaoka pilot site. Presented at the IEA GHG Monitoring Network, 2 June 2009, Tokyo, http://www.co2captureandstorage.info/networks/monitoring.htm.

[24] IPCC Special Report on Carbon Capture and Storage (2005), Chapter 5, pp. 225-230.

[25] IPCC Special Report on Carbon Capture and Storage (2005), Technical Summary, p. 33.

[26] The Convention on the Prevention of Marine Pollution by Dumping of Wastes and Other Matter, 1972, and 1996 Protocol thereto.

[27] The 1992 Convention for the Protection of the Marine Environment of the North-East Atlantic.

[28] DIRECTIVE 2009/31/EC OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 23 April 2009 on the geological storage of carbon dioxide and amending Council Directive 85/337/EEC, European Parliament and Council Directives 2000/60/EC, 2001/80/EC, 2004/35/EC, 2006/12/EC, 2008/1/EC and Regulation (EC) No 1013/2006.

94. The First and Second Synthesis Reports reflect a broad agreement in parties' submissions that site characterisation and selection is the most critical element in ensuring long-term or permanent CO_2 storage from CCS with frequent references to conclusions from the IPCC SR and recommendations provided in the 2006 IPCC Guidelines[29] [30]. Parties agree that characterisation should, inter alia, determine a geological formation's capacity to trap CO_2 including identifying and quantifying relevant properties of the formation, identifying and characterising potential seepage pathways. The importance of modelling in this context is underlined by the First Synthesis Report[31].

95. There is a strong scientific and technical knowledge base regarding the selection and approval of CO_2 secure storage sites and institutional and legal experiences are emerging. <u>It is recommended that the Board consider developing criteria for the assessment of site selection and approval, including risk assessment, drawing on the existing knowledge base. For any proposed geological CCS CDM methodologies and project activities, the site characterisation and selection should be fully described. The assessment of the site characterisation and selection would require a DOE with appropriate CCS expertise.</u>

Operation of Reservoirs and Remediation

96. Several Parties and Organisations in their submissions underline that proper management of CCS projects is of utmost importance in minimising fugitive emissions from CO_2 capture, transportation and injection as well as seepage and, furthermore, the importance of appropriate monitoring programmes and approaches related to prevention of fugitive emissions and seepage[32].

97. The IPCC SR states that careful storage site selection, design and operation, together with methods for early detection of seepage, are effective ways of reducing hazards associated with diffuse seepage[33]. Geological storage projects should always be selected and operated to avoid seepage. However, in the event seepage should occur remediation techniques are available to stop or control them.

98. The presence of impurities in the CO_2 gas stream has an impact on the engineering process of injection, e.g. by affecting the compressibility of the injected CO_2. Furthermore, gas impurities in the CO_2 stream take up available storage space. Impurities also affect trapping mechanisms and the storage capacity depending on the type of geological storage. Thus, the presence of impurities must be considered in the overall storage assessment and design.

99. The IPCC SR emphasizes that monitoring is a very important part of the overall risk management strategy for geological storage projects. The IPCC SR provides detailed descriptions of relevant parameters to monitor as well as applicable monitoring techniques, including, injection rate and injection well pressure, repeated seismic surveys for tracking the underground migration of CO_2, sampling of groundwater and the soil between the surface and water table for directly detecting CO_2 seepage, and CO_2 sensors at the injection wells for detecting seepage. There are a range of available measurement techniques for detection and quantification of seepage from geological storage, although their accuracy is

[29] FCCC/SBSTA/2008/INF.1, Paragraph 37.
[30] FCCC/SBSTA/2008/INF.3, Paragraph 24.
[31] FCCC/SBSTA/2008/INF.1, Paragraph 41.
[32] FCCC/SBSTA/2008/INF.1, Paragraphs 19-21.
[33] IPCC Special Report on Carbon Capture and Storage (2005), Chapter 5, pp. 251-252.

site and situation specific. Such techniques are being tested on controlled release experiments such as ZERT in the USA and ASGARD in the UK, as well as on natural CO_2 seepages in Germany and Italy[34]. Furthermore, baseline data improve the reliability and resolution of all measurements and will be essential for detecting small rates of seepage. A framework for monitoring of geological CO_2 storage projects is provided in the 2006 IPCC Guidelines and is discussed in the section on Methodological issues in this report. Initial listings of monitoring techniques can be found in the 2006 IPCC Guidelines and the IEA GHG web site (Monitoring Selection Tool)[35].

100. The First Synthesis Report[36] underlines the role of monitoring results for recalibration of models used for predicting the behaviour of CO_2 injected into a geological formation, thus expanding the knowledge base for risk assessment and optimisation of operation.

101. In terms of remediation the IPCC SR provides an overview of remediation options for a range of seepage scenarios[37]. Possible remediation measures are furthermore highlighted in the First Synthesis Report[38]. These techniques could involve standard well repair techniques or the extraction of CO_2 by intercepting its leak into a shallow groundwater aquifer.

102. <u>For any proposed geological CCS CDM methodologies, seepage remediation options should be described in connection with an analysis of the most likely seepage scenarios. The assessment of the remediation plan would require a DOE with appropriate CCS expertise.</u>

Emission Categories from Geological CCS Projects

103. The First Synthesis Report[39] comprehensively lists emission categories from CCS projects that would all be relevant in relation to the estimation of project emissions in a geological CCS CDM methodology:

(a) Fugitive emissions (above ground physical leakage of CO_2 from the capture, transport and injection system

(b) Indirect emissions (resulting from the use of energy for the CCS project)

(c) Seepage emissions (gradual long-term physical leakage from the storage site)

(d) Storage site breach (sudden release of CO_2 from the storage site)

104. Methods for estimating emissions under the (a), (c) and (d) categories are provided in the 2006 IPCC Guidelines[40]. Emissions under (b) can be estimated by standard approaches already applied under the CDM.

[34] There are indications from certain initial results that techniques may be able to quantify seepage to the levels required for emissions accounting. However, further research is necessary to improve understanding of leakage quantification.
[35] http://www.co2captureandstorage.info/co2tool_v2.2.1/index.php.
[36] FCCC/SBSTA/2008/INF.1, Paragraph 47.
[37] IPCC Special Report on Carbon Capture and Storage (2005), Chapter 5, Table 5.7.
[38] FCCC/SBSTA/2008/INF.1, Paragraphs 19 and 22.
[39] FCCC/SBSTA/2008/INF.1, Paragraph 13.
[40] 2006 IPCC Guidelines for National Greenhouse Gas Inventories (2006), Vol 2, Chapter 5.

Uptake of CCS

105. CCS leads to an increase in capital and operating expenses, combined with a decrease in plant energy efficiency. Costs of CCS vary depending on a large number of factors including the type of emission source, the type of capture technology, mode of transportation and transportation distance, the type of geological storage used, the required CO_2 purity and whether CCS is designed to apply to an existing, or new, system[41]. In most relevant cases CO_2 capture dominates the cost of CCS and it is therefore crucial whether CO_2 separation is carried out as an inherent part of the process or not. As mentioned above, some industrial processes already involve CO_2 separation. Thus the cost of separation for certain "process emissions" is non-existent – in such cases, when the baseline means venting the CO_2 into the atmosphere, the additional cost is the compression, transport and storage. In certain cases CCS activities may also have some economic benefits beyond climate change mitigation, e.g. EOR activities or decreased local air pollution. The relative costs or benefits of different types of CCS activities will affect their likelihood of being undertaken in a business-as-usual scenario, and thus their additionality under the CDM.

106. Commercial CCS projects in the power sector are more realistic on the longer-term. This is supported by cost estimates by the IPCC[42] and the IEA[43], among others. According to the most recent predictions, and in terms of cost per tonne of CO_2 avoided[44], near-term costs for CO_2 capture and storage for coal-fired power plants are quite high, dropping to USD 50-65 in 2030. For gas-fired power plants costs are generally higher, predicted to drop to USD 55-90 in 2030. Therefore, it is necessary to look beyond the power sector to identify near-term opportunities for CCS. CO_2 capture from natural gas processing, ethanol production and fertiliser production, as well as production of hydrogen and other fuel transformation processes, can provide near-term opportunities with lower costs than capture from power plants.[45] On the other hand, the widespread adoption of CCS in other industries, such as iron, cement, and pulp and paper, is likely to require decades as core processes will need to be redesigned or similar challenges related to CO_2 separation as in the power sector are faced, albeit even more pronounced,.

The IEA/OECD[46] compiled technical potentials for CCS from several activities in non-Annex I countries (Table 2). Some of these activities could be carried out as business-as-usual activities (e.g. for enhanced oil recovery), whereas others would not (e.g. retrofitting power stations to capture and store CO_2). In the short term, the potential is likely made of EOR activities and capture from point sources where the CO_2 is inherently separated from other materials in the process, e.g. in ammonia plants, hydrogen plants, and natural gas processing.

[41] IPCC Special Report on Carbon Capture and Storage (2005), Chapter 3.
[42] IPCC Special Report on Carbon Capture and Storage (2005).
[43] IEA. CO2 Capture and Storage – A key carbon abatement option. Paris, 2008.
[44] Thus taking into account the impact of efficiency losses etc, as opposed to the cost of CO2 captured.
[45] IEA. CO2 Capture and Storage – A key carbon abatement option. Paris, 2008.
[46] IEA/OECD, Carbon Capture and Storage in the CDM (2007).

Table 2. Short and long-term technical potential for CO_2 capture in non-Annex I countries, selected industries

	Million tonnes CO_2/y	
	To 2012	2020
Hydrogen production	7	7
Refineries	322	322
Ammonia production	78	78
New coal-fired electricity	-	2193
Retrofit of fossil-fired power stations	-	5077
Retrofit of cement factories	-	1270
Natural gas processing	167	334
Enhanced oil recovery	10	20
Total	**584**	**9301**

107. The estimated 2020 technical potential for the volume of CO_2 capture from these activities in non-Annex I countries is quite large: 9.3 billion tons of CO_2 (Table 2). The corresponding 2012 potential is much smaller, at 584 million tons CO_2 per year by 2012. Note, however, that the bulk of the long-term potential is for activities associated with high costs (power sector and cement manufacturing).

108. With respect to regional issues, it can be concluded based on the information in Table 2 that a vast share of the near-term potential for CO_2 capture can be found in oil- and gas-producing regions. The economics will be particularly favourable when and where there are opportunities for EOR. The IEA[47], however, notes that, with some exceptions, regions with vast potentials for CO_2-EOR are generally not close to large CO_2 emission nodes. It can furthermore be concluded from Table 2 that a large share of the estimated 2020 technical potential for CO_2 capture is associated with emissions from the power sector, with the implication that large coal-based emerging economies represent a significant share of the potential.

109. It can thus be concluded that the greatest technical challenge associated with creating the necessary conditions for the widespread deployment of CO_2 capture and storage is to reduce the capture costs for low-concentration and -pressure emission sources abundant globally primarily in the power sector. Intensified development aims at fostering improved capture technologies for such sources. The maturity of these technologies ranges from experimental to demonstration level. Furthermore, in order to enhance the potential in the industrial sector, capture technologies for specific industries such as cement, steel and oil refineries must be tailored to the specifics of the production process.

D. <u>Methodological Issues</u>

Monitoring and Verification

110. Given the primary objective of CCS in terms of CO_2 emission reduction, the primary purpose of monitoring is to verify that it is satisfying this objective. The 2006 IPCC Guidelines[48] provides the overarching framework for monitoring and verification of CO_2 geological storage, both in terms of GHG

[47] IEA. CO2 Capture and Storage – A key carbon abatement option. Paris, 2008.
[48] 2006 IPCC Guidelines for National Greenhouse Gas Inventories , Vol 2, Chapter 5 http://www.ipcc-nggip.iges.or.jp/public/2006gl/index.html.

mitigation performance but also implicitly for wider general environmental integrity. The methodology provided (a Tier 3 methodology based on site characterisation, modelling and monitoring) states that zero seepage can be assumed for appropriately selected and managed sites if the evidence from modelling and monitoring indicates so. The methodology is non-prescriptive on monitoring techniques because it recognises that every storage site is geologically different. This GHG methodology could also be applied to CCS project activities under the CDM as their primary purpose is reduction of GHG emissions. This means that the monitoring programme and techniques selected for any CCS project activities under the CDM should be determined by the site characterisation and modelling of the CO_2 behaviour in advance (which is of utmost importance so as to enable that only environmentally sound sites are selected) and will therefore be site specific. Different monitoring techniques have different applicability for different geological situations, which means that there should be flexibility in the monitoring programme details, whilst setting the overall objectives. This allows the most appropriate monitoring techniques to be selected for each site. This principle of flexibility is also demonstrated in recent legislation for CCS such as the London Protocol[49], OSPAR[50], the EU Directive[51], the US EPA Draft Rule[52], and the Australian Commonwealth and State legislation[53] [54] [55]. These all have the primary objective of monitoring to verify the performance of the site, and to detect seepage should it occur. In the EU and IPCC GHG cases additional monitoring is required to then quantify seepage amounts. Some of this legislation also requires that should seepage occur, then monitoring should be used to assess the environmental impacts. Whilst this isn't necessary for GHG accounting purposes, for good environmental practice it would be advisable to include this in monitoring programmes for any CCS project activities under the CDM. A range of monitoring techniques exists for all these objectives, see further the section on Technical issues in this report.

111. New Monitoring Methodologies would need to be created for any CCS project activities under the CDM, and it is recommended that all CCS Monitoring Methodologies should follow the same four objectives of performance monitoring, seepage detection, seepage quantification and seepage impact assessment, with the latter two objectives only being triggered if leakage is detected or suspected from the monitoring results of the first two objectives (as treated in the London Protocol, OSPAR and the EU CCS Directive). This approach would apply to all geological storage formations and sites. For each project, the monitoring methodology, programme, and techniques should be derived from the site characterisation and modelling for the particular site, and fully described in the PDD so that they can be assessed. An important requirement is that the monitoring results during project operation are used to check against the

[49] The Convention on the Prevention of Marine Pollution by Dumping of Wastes and Other Matter, 1972, and 1996 Protocol thereto.

[50] The 1992 Convention for the Protection of the Marine Environment of the North-East Atlantic.

[51] DIRECTIVE 2009/31/EC OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 23 April 2009 on the geological storage of carbon dioxide and amending Council Directive 85/337/EEC, European Parliament and Council Directives 2000/60/EC, 2001/80/EC, 2004/35/EC, 2006/12/EC, 2008/1/EC and Regulation (EC) No 1013/2006.

[52] EPA-HQ-OW-2008-0390. Federal Requirements Under the Underground Injection Control (UIC) Program for Carbon Dioxide (CO2) Geologic Sequestration (GS) Wells.

[53] Offshore Petroleum and Greenhouse Gas Storage Act 2006. Act No. 14 of 2006 as amended. 23 February 2009. Office of Legislative Drafting and Publishing, Attorney-General's Department, Canberra (Australia).

[54] Greenhouse Gas Geological Sequestration Act 2008.. The Parliament of Victoria (Australia).

[55] Greenhouse Gas Storage Act 2009. The Parliament of Queensland (Australia).

ex ante modelling of CO_2 behaviour, and the modelling improved ex post if necessary, the results of which may then suggest modifications to the monitoring programme. Therefore, it is recommended that within the context of subsurface element of a CCS CDM methodology/ies there should be a periodic requirement for the revised modelling results to be re-assessed by the DOE.

112. In addition to this storage-related monitoring there will be monitoring of emissions related to the surface-related project activity, i.e. the combustion or process emissions, transport, etc, as would be expected with any other CDM projects.

The assessment of a monitoring programme (in the PDD) would require a DOE with appropriate CCS expertise. It is recommended that DOEs wishing to validate CCS projects would have to be accredited with this expertise, which would require a new sectoral scope be introduced in the CDM.

113. CCS projects differ from other CDM activities in one fundamental way; the potential for long-term seepage of CO_2 will by far outlast the CDM project crediting period. Thorough understanding of the permanence issue requires advanced expertise in complex technical areas. Since such expertise is generally not represented among Board members or its panels and working groups it is recommended that, if CCS is considered eligible under the CDM, the Board establishes a CCS Working Group. The Working Group shall have the mandate to support the Board on technical issues related to the permanence of CO_2 storage in geological formations, including, eg., accreditation of DOEs to validate CCS projects, supporting the Board in developing criteria for the assessment of CO_2 storage site selection and approval, and preparing recommendations on technical matters related to the permanence of CO_2 storage in submitted proposals for new baseline and monitoring methodologies. The establishment of a CCS expert group under the Board was also supported by Parties in their submissions (First and Second Synthesis Reports).

114. The First Synthesis Report provides a listing of the elements to be included in a monitoring programme[56], derived from the IPCC GHG Guidelines. It is recommended that these should be followed in any CCS CDM methodologies.

115. For the purposes of GHG accounting, the primary measurements of CO_2 quantity are likely to be made using mass-balance measurement techniques, which will determine overall net fugitive emissions from the transport and injection stages and the quantities of CO_2 injected to storage. However if seepage from geological storage should occur, there is potentially more uncertainty about the accuracy of seepage quantification. For CO_2 storage site seepage, it is recommended that any uncertainty in quantification needs to be addressed to avoid underestimating actual seepage emissions. It is important to be conservative and so err on the side of overestimation rather than underestimation. An example of how to apply this conservative principle is provided by the EU ETS Monitoring and Reporting Guidelines for CCS[57]. In these, if the uncertainty is above a specified level for the measured emissions of seepage, these measured emissions will be multiplied by an 'uncertainty supplement'. In the EU case this is set for a maximum uncertainty of 7.5%, and if this cannot be achieved then measured emissions are multiplied by an uncertainty supplement of:

[56] First Synthesis Report, Paragraph 49.

[57] Commission decision Draft amending Decision 2007/589/EC as regards the inclusion of monitoring and reporting guidelines for greenhouse gas emissions from the capture, transport and geological storage of carbon dioxide.

$CO_{2,Reported}$ [t CO_2] = $CO_{2,Quantified}$ [t CO_2] * (1 + ($Uncertainty_{System}$ [%]/100) – 0.075)

With

$CO_{2,Reported}$: Amount of CO_2 to be included into the annual emission report with regards to the seepage event in question

$CO_{2,Quantified}$: Amount of CO_2 determined through the used quantification approach for the seepage event in question

$Uncertainty_{System}$: The level of uncertainty which is associated to the quantification approach used for the seepage event in question.

116. Also, in temporal terms, to avoid underestimating the seepage amounts, the EU ETS Monitoring and Reporting Guidelines proposes that seepage is assumed to have occurred over time dating back to when evidence shows there wasn't a seepage event or by default back to the date on injection, unless other evidence indicates otherwise.

117. <u>It is recommended that any new Monitoring Methodologies for CCS in the CDM should use the same factors so as to avoid underestimating seepage amounts</u>.

118. To safeguard the environmental integrity of any CCS project activities under the CDM, monitoring of storage sites should continue after site closure and the end of the CDM crediting period, although this monitoring can be reduced if evidence indicates the CO_2 is "approaching its predicted long-term distribution" with no suggestion of potential seepage (as stated in the IPCC GHG Guidelines, and also in the EU Directive). If the site is still in the responsibility of the operator this monitoring is a straightforward requirement. If the site has transferred to a state authority, then sufficient monitoring should still continue so as to detect seepage events for a period. In the EU, the indicative time period for the post-closure monitoring by the operator is at least 20 years and subsequently by the competent authority (ie state) 30 years, subject to revision (greater or smaller) depending on the monitoring results. This monitoring should not be a burden on the state, and the EU model is that the project operator creates a financial mechanism for the amount required to cover the monitoring for this duration. <u>It is recommended that the Board considers requirements for monitoring post closure and post CDM crediting period for any proposed geological CCS CDM methodologies regardless of whether the storage site is in the responsibility of the operator or if the responsibility has been transferred to a state authority</u>. A range of financial mechanisms exist, including investment in a fund, allocation of a percentage of CERs. Rather than being prescriptive, it could be left to the project proponent to choose what suits their situation most appropriately. This also means that the temporal project boundary has to include this post-liability transfer phase.

Regulatory Requirements

119. In addition to GHG performance, best practice suggests that regulatory control of any CCS project will be needed in order to ensure appropriate protection of human health and the environment. The risk and potential consequences of CO_2 seepage in this context should be assessed as part of regulatory approaches, and should also be described in the PDD or relevant accompanying documentation such as Environmental Impact Assessments (EIAs). Several examples now exist of such regulatory control for CCS from different countries, all similar in their principles and requirements (e.g. Australia,

USA, Japan, EU). The minimum requirements could be that CO_2 storage is not allowed without a permit from a responsible regulatory authority in the host country. Regulatory best practice now shows that permit applications should include a risk assessment (including the site characterisation and modelling), monitoring plans, remediation plans (in the event of seepage), and closure plans. The EU Directive provides an example that covers all aspects of all parts of the CCS chain, from capture to storage, and all the elements mentioned above. Regulation of CCS in the host country with an appropriate regulatory body to administer it is highly important. It is recognised that it may take time and resources for a host country to develop regulation to the degree and detail that exists in the examples mentioned and support to facilitate such developments may be considered. For example, an International framework for best-practice could be established.

120. An objective of any DOE validating a CCS CDM project activity would be to assess whether there is a sufficient regulatory framework in place in the host country to control the project, and whether the appropriate regulatory approval has been or can be given to the particular project. It may be difficult to coordinate the timing of this approval, but some form of indication of support from a regulatory authority should be required as part of CCS CDM project Registration.

121. An expert panel set up by the Board may be able to advise the host regulatory authority on key issues. Advise should apply to relevant regulatory requirements, including international regimes on transboundary issues if relevant.

Other Methodological Issues - Project Boundaries

122. Whilst not explicitly specified in the ToR for this task, the issue of project boundaries should be addressed. In terms of spatial boundaries, the First Synthesis Report indicates that there is clarity amongst Parties on all the aspects of a CCS project which should be included within the project spatial boundary, i.e. all aspects from capture, transport and storage. Thus, the project boundary should comprise both above ground and below ground components, including a larger volume than just the storage reservoir so as to include potential secondary containment formations. For example, the EU Directive defines this larger volume a ‘storage complex’ as being the storage site and surrounding geological domains which can have an effect on overall storage integrity and security (ie secondary containment formations). Whilst one Party in the Second Synthesis Report considers that for CCS the project boundaries could be dynamic which would not be consistent with the CDM, using a good site characterisation and modelling, together with inclusion within the boundary of a storage complex, could be considered sufficient for projects to be able to proceed in the CDM. In the event that CO_2 does move out of the project spatial boundary, the PDD should be revised and reassessed by the DOE and the Board, with the option of changing the spatial boundary as the most important thing is to ensure all potential seepage locations are included within the project boundary.

123. In terms of project temporal boundary, this should recognise that there is the potential for seepage after the CDM crediting period and after project closure until evidence indicates that the CO_2 plume is stabilising at its long term distribution, and even potentially after liability transfer to a host country. Therefore the project temporal boundary should include all of the above up to the end of a monitoring period undertaken by a responsible entity after liability transfer. Monitoring activities carried out by the host country could be reported in its National Communications to the UNFCCC, following IPCC Guidelines applicable at the time.

E. Legal Issues

Risks and Liabilities - Potential CO_2 Seepage

124. CCS projects differ from other CDM activities in terms of the types of risk presented, as the potential for long-term seepage of CO_2 will outlast the CDM project crediting period. To keep this in context, all the evidence and expert judgement suggests (IPCC SR, 2006 IPCC GHG Guidelines, etc) that with appropriate site selection and operation, this risk should be extremely small (for further detail, see the Technical section in this report). Accordingly, the 2006 IPCC Guidelines state that its Tiers 3 methodology can be implemented to support zero emission estimates from appropriately selected and managed CO_2 storage sites. However, this risk of seepage, even if extremely small, would still have to be addressed to assure of the environmental integrity of the CDM if CCS were made eligible as CDM project activities.

125. The 2006 IPCC Guidelines established the principle that CO_2 transferred to a CO_2 storage site counts as not emitted, which is followed by the revised EU ETS Directive. To be precise, the EU ETS Directive states "An obligation to surrender allowances shall not arise in respect of emissions verified as captured and transported for permanent storage to a facility for which a permit is in force in accordance with Directive 2008/xxx/EC on the geological storage of carbon dioxide"[58]. This used the requirements of the EU CCS Directive to ensure environmentally sound storage is undertaken, and only then is the CO_2 storage performance acknowledged in the EU ETS system. Within the EU ETS system, if there are subsequent seepage emissions from storage, then the storage operator has to surrender emission allowances equivalent to the seepage amount, i.e. as with any emissions from any facility covered by the ETS. However what would be different in the case of emissions from storage seepage is that once surrendered these allowances are removed from the system by the relevant authority to ensure the integrity of the ETS. It is recommended that this principle be applied for CCS CDM projects also, in the short and long-term.

126. During the crediting period of a CCS project under the CDM, the liability for CO_2 seepage should reside with the operator. Any seepage amounts should be treated as project emissions. Potentially, this could mean that the operator would have to purchase CERs on the market to surrender appropriate amounts if the seepage amounts exceed the net storage amounts for one monitoring/verification period, for example if injection activity has ceased operation. National regulations could also require that the seepage source is remediated. Liability for safety and environmental damage could be dealt with through appropriate national regulations, although compensation arrangements can be included in the project design.

127. After the CDM project crediting period, there would have to be a means of ensuring the environmental integrity of the CDM is maintained in the event of seepage. The basic requirement should be that CERs (or equivalent at the time) equal to the quantity of seepage CO_2 should be surrendered by an entity responsible for the project to the UNFCCC CDM Registry Account, and the seepage source would

[58] DIRECTIVE 2009/29/EC OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 23 April 2009 amending Directive 2003/87/EC so as to improve and extend the greenhouse gas emission allowance trading scheme of the Community.

be remediated. This has to be taken in the context that the natural trapping mechanisms for CO_2 in geological formations means that security of storage increases over time. The IPCC and the First Synthesis Report identify many remediation options (see Technical section), all with their merits. There is a widely held view by many Parties that the ultimate liability should be with the host country, as they have ultimate responsibility in terms of regulatory approval, site ownership and jurisdiction over the site. However, the risk can be reduced or removed from host countries with the use of instruments such as long-term financial bonds or insurance or contractual arrangements with the project operator. Given the range of options open, and the limited number of projects expected in developing countries during the first and a second commitment period, it is suggested that at this early stage, if CCS were allowed in the CDM and assuming long-term liability transfer to the host country, host countries should be allowed to choose their liability transfer and funding mechanisms, so as to allow 'learning' from the early projects, to see what works best for the approval by the relevant bodies. It is suggested that the quantification of the liability funding mechanism be determined either at the point of project closure or at the point of liability transfer when the original risk assessment should be revisited and updated. However, it is recommended that the DOE and the Board would need to be satisfied with the outline arrangements to undertake this, which should be detailed in advance in the post-closure plan in the PDD, and to give their approval or not.

128. Seepage in the longer term after the CDM crediting period should have the same principle apply of surrendering of CERs for the seepage amount, as described previously. A range of options and issues for how this accounting could be managed are provided in the Second Synthesis Report [59] (although dealt with as a policy issue). Keys ones to recommend are that accounting rules should be consistent with current rules under the CDM, and CERs should be as permanent and fungible as those from other project activities. In addition, relying on temporary or discounted CERs to allow for potential seepage at some point in time would reduce or remove the incentive to manage and ensure long-term integrity that comes from the penalty of having to surrender CERs equal to seepage amounts. Again, because of the limited number of projects possible in developing countries during the first and a second commitment periods, it could be left to project operators and host countries to propose the option to manage the post-CDM-project accounting that suits them best, for evaluation by the Board, so long as the fundamental principle of surrendering CERs for the seepage amount is made obligatory.

129. Liability for safety and environmental damage should be dealt with through appropriate national regulations, although compensation arrangements can be included in the project design. For transboundary issues see the section below.

Other Legal Issues

Kyoto Protocol

130. In the Second Synthesis Report, several Parties question the compatibility of CCS with the Kyoto Protocol, whilst others consider it compatible. In the Kyoto Protocol Article 2 paragraph 1(a)(iv)[60] mitigation technologies with the characteristics of CCS are recognized and encouraged for Annex 1 countries to use, and furthermore CCS does not have a 'refrain' from usage within the CDM placed upon

[59] Second Synthesis Report, paragraph 58.
[60] KYOTO PROTOCOL TO THE UNITED NATIONS FRAMEWORK CONVENTION ON CLIMATE CHANGE. UNITED NATIONS 1998. http://unfccc.int/resource/docs/convkp/kpeng.pdf.

it by the Marrakesh Accords as they do for nuclear facilities[61]. Therefore, CCS can be assumed to be not incompatible with the Kyoto Protocol, so further examination of these issues will not be undertaken here.

Local

131. In terms of requirements from the host country, a general point is that a host country should have in place an adequate regulatory regime to ensure environmentally sound CCS projects, see the Regulatory Requirements section of the Monitoring Section previously. There should also be legal clarity over ownership of the pore space that is to be used for the CO_2 storage.

International Boundary Issues

132. Concern over the legal implications of storage and seepage which cross national boundaries and in international waters was raised by several Parties in the Synthesis Reports. Whilst the 2006 IPCC Guidelines do provide guidance on the responsibilities in terms of reporting emissions from storage which crosses national boundaries (e.g., the Second Synthesis Report, paragraph 64), and this could be mirrored by the responsibility for surrendering CERs (or equivalent) in the event of seepage, this would still create an additional legal relationship and responsibility to be implemented and enforced, involving DNAs from more than one country. Additional complexities arise if one country is not a Party to the Kyoto Protocol or doesn't have a DNA.

133. In terms of storage beneath international waters, this is unlikely to occur as the spatial extent of national jurisdictions are limited to continental shelves, beyond which the water depths increase significantly and therefore much more difficult and costly for injection and storage of CO_2 than in shallower continental shelf waters.

134. In terms of offshore storage, the London Protocol Article 6 currently prohibits cross-boundary transport of CO_2 for geological storage in the marine area, and there is uncertainty also regarding the intended migration across boundaries. This arises under the general prohibition on export of all wastes for dumping (Article 6). The London Protocol has been investigating the legal issues of cross-border transport and storage. To resolve this prohibition, the Government of Norway has proposed an amendment to the London Protocol Article 6[62], for consideration and adoption at the annual meeting in October 2009. This amendment proposes that the receiving state gives prior consent, and that both states apply the London Protocol's CO_2 Sequestration Guidelines (detailed guidelines to regulators when permitting on risk assessment and management[63]). This amendment is based upon the deliberations and conclusions of a working group over 2008-9. However, if this amendment is adopted, it will require

[61] The Marrakesh Accords.

[62] CO2 SEQUESTRATION IN SUB-SEABED GEOLOGICAL FORMATIONS: CO2 SEQUESTRATION IN TRANSBOUNDARY SUB-SEABED GEOLOGICAL FORMATIONS. Proposal to amend Article 6 of the 1996 Protocol to the Convention on the Prevention of Marine Pollution by Dumping of Wastes and Other Matter, 1972. Submitted by Norway. THIRTY FIRST CONSULTATIVE MEETING OF CONTRACTING PARTIES TO THE LONDON CONVENTION & FOURTH MEETING OF CONTRACTING PARTIES TO THE LONDON PROTOCOL. 26 – 30 October 2009.

[63] RISK ASSESSMENT AND MANAGEMENT FRAMEWORK FOR CO_2 SEQUESTRATION IN SUB-SEABED GEOLOGICAL STRUCTURES (CS-SSGS).Source LC/SG-CO2 1/7, Annex 3. Adopted at the joint session of the 28th Consultative Meeting of Contracting Parties under the London Convention and the 1st Meeting of Contracting Parties under the London Protocol (30 October - 3 November 2006).

ratification by two thirds of Parties before coming into force, so it could be some time before this prohibition is removed. Failure to amend the London Protocol may constrain some countries ability to implement CCS projects, where they may not have sufficient storage capacity within their national boundaries.

135. Due to additional legal implications for cross-border storage it is suggested that CCS projects in the first and a second commitment period would be limited to take place within national boundaries and with no risk of migration across national boundaries. This suggestion is also supported by some Parties in The First and Second Synthesis Reports.

F. Environmental Issues

136. Impacts of carbon capture and storage technologies on the environment and human health are potential issues that have to be considered in CCS CDM activities. It should be noted that these potential environmental impacts are linked with the overall characteristics of CCS projects and are independent of whether they are implemented as a CDM project activity or not. However the prevention and the treatment of potential environmental impacts if CCS projects are implemented under the CDM should be treated in the same way as for other CDM project activities. Several Parties draw attention to environmental impacts in the two Synthesis Reports.

CO_2 Impurities

137. An environmental point mentioned in the First Synthesis Report is related to impurities in CO_2 streams. It was suggested that no waste or other matter should be added to a stream for the purpose of discarding that waste or other matter. However, it was argued that CO_2 streams for injection may contain incidental associated substances derived from the source material and the capture, transport and storage processes used.

138. It was also suggest by Parties that the acceptable concentration of any substance should depend on its potential impact on the integrity of the storage site, on relevant transport infrastructure, on the risk to the environment and on requirements of the applicable regulations. Is was suggested that potential operators of CCS projects under the CDM prove that their CO_2 streams are sufficiently pure and that they have adequately considered the relationship between CO_2 stream purity and the surrounding cap rock, including environmental and other risks of CO_2 storage.

139. It is worth noting that these overall recommendations are in line with recent amendments to the London Convention and OSPAR where CO_2 stream purity is addressed: "CO_2 stream consist overwhelmingly of CO_2. May contain incidental associated substances"..."Concentration should be related to potential impacts on integrity of storage and transport..."

140. It can further be remarked that it is in line with the European Directive on Storage[64], and particularly with Article 12 "CO_2 stream acceptance criteria and procedure". The European Directive considers that "CO_2 stream shall consist overwhelmingly of carbon dioxide." (...) "no waste or other matter may be added for the purpose of disposing of that waste or other matter." It was recognized that "CO_2 stream may contain incidental associated substances from the source, capture or injection process

[64] DIRECTIVE 2009/31/EC OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 23 April 2009 on the geological storage of carbon dioxide.

and trace substances added to assist in monitoring and verifying CO_2 migration". Furthermore, these concentrations (of all incidental and added substances) shall be "below levels that would: adversely affect the integrity of the storage site or the relevant transport infrastructure; pose a significant risk to the environment or human health; or breach the requirements of applicable Community legislation." To be in line with this objective it is accepted that European Member States shall ensure that the operator: "accepts and injects CO_2 streams only if an analysis of the composition, including corrosive substances, of the streams and a risk assessment have been carried out, and if the risk assessment has shown that the contamination levels are in line with the conditions referred (...)"; it is also proposed that a register of the quantities and properties of the CO_2 streams delivered and injected shall be kept, including the composition of those streams.

141. <u>If CCS is considered eligible under the CDM it is recommended that no waste or other matter may be added to a CO_2 stream of a CCS CDM project activity for the purpose of discarding that waste or other matter and that acceptable levels of impurities in CO_2 streams be determined based on its potential impacts on transport and storage integrity. It is furthermore recommended that that operators of potential CCS projects under the CDM prove that their CO_2 streams are sufficiently pure and that they have adequately considered the relationship between CO_2 stream purity and the surrounding cap rock, including environmental and other risks of CO_2 storage.</u>

Environmental Impact Assessment

142. Another point mentioned in the Synthesis Reports is the environmental effects of seepage from sub-seabed and onshore storage sites. It was requested by Parties that environmental conditions in the vicinity of the planned storage site and their sensitivity to potential CO_2 seepage have to be taken into account in site selection.

143. There was broad agreement across several Parties and organizations that any methodology applicable to CCS as a CDM project activity would need to incorporate at least: a thorough risk assessment of the storage site and operation, including an assessment of all potential seepage paths and environmental impacts, using detailed site characterization and simulation techniques.

144. All these recommendations could hold attention. Indeed in a 2009 publication[65], the IEA GHG Risk Assessment network indicates that Environmental Impact Assessments of seepage can provide the framework for assessment of long term impacts. However, it is also noted that "there was little research underway to assess the potential effects of CO_2 leaks that could allow an Environmental Impact Assessments to be compiled, and an agreement was reached (in meetings) to address this knowledge gap." The IEA GHG Risk Assessment network agrees for the future development of risk assessment methodology that "demonstration projects will be a significant source of information". When future developing demonstration projects will be built, risk assessment should be consolidated. In the interim period, "natural and industrial analogues may be used as sources of information and to generate confidence in geological storage of CO_2 as a safe and environmentally acceptable global warming

[65] Energy Procedia 1 (2009) 2581–2586, GHGT-9, An Introduction to the IEA GHG International Research Network on Risk Assessment, Brendan Beck and Toby Aiken, IEA Greenhouse Gas R&D Programme.

mitigation option". IEG GHG Risk Assessment Network launches the construction of a risk assessment database (See reference in the meeting report (cf. Table 3 p. 17) [66]).

145. At the European level, the Directive 2009/31/EC[67] indicates that the "Directive 2008/1/EC[68] concerning integrated pollution prevention and control[69] is suitable for regulating, in respect of certain industrial activities, the risks of CO_2 capture to the environment and human health ..."; and in §(19) it is noted: "Member States should, in selecting storage sites, take account of their geological characteristics (...). A site should therefore only be selected as a storage site, if there is no significant risk of leakage, and if in any case **no significant environmental or health impacts** are likely to occur. This should be determined through a characterisation and assessment of a potential storage complex pursuant to specific requirements."

146. It is recommended that the Environmental Impact Assessment carried out for each potential CCS project under the CDM, albeit governed by national regulations, should be based on the risk assessment procedure that should be outlined in any CCS CDM methodology and PDD.

Other Impacts and Benefits

147. Concerning CCS impacts and benefits, one organization mentioned in the Second Synthesis Report that application of CCS in coal-fired power plants in developing countries could have the **added benefit** of reducing air pollution and negative health impacts as well as acid rain.

148. In general, this opinion seems to be shared by several publications[70] especially with regard to SO_2. However, emissions of NO_X are dependent on several parameters: fuel quality, plant configuration, scrubbing sections in the plant and capture technology used. This issue will be addressed within the context of the general Environmental Impact Assessment.

149. Another point mentioned in the First Synthesis Report is that environmental impact concerns should be addressed in line with the **CDM modalities and procedures**. This requires project participants to submit specific documents: an analysis of the environmental impacts of projects; an environmental impact assessment should the impacts be considered significant by the project participants or host country.

150. A process for defining the potential environmental, health and safety impact assessment of a CCS project activity under the CDM has been proposed[71] that shall ensure a high level of environmental

[66] "Launch Meeting of the Risk Assessment Network. 23, 23 August 2005. Organized by IEA-GHG R&D Program and TNO NITG, with the support of EPRI. http://www.co2captureandstorage.info/docs/risk/rareport05.pdf.
[67] OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 23 April 2009 on the geological storage of carbon dioxide and amending Council Directive 85/337/EEC, European Parliament and Council Directives 2000/60/EC, 2001/80/EC, 2004/35/EC, 2006/12/EC, 2008/1/EC and Regulation (EC) No 1013/2006.
[68] of the European Parliament and of the Council of 15 January 2008.
[69] OJ L 24, 29.1.2008.
[70] For example: "The impacts of CO2 capture technologies on transboundary air pollution in the Netherlands", Toon van Harmelen (TNO), Joris Koornneef (UU), Arjan van Horssen (TNO), Andrea Ramírez Ramírez (UU), René van Gijlswijk (TNO), May 2008.
[71] IEA Greenhouse Gas R&D Programme, "ERM – Carbon Dioxide Capture and Storage in the clean development mechanism", 2007/TR2, April 2007.

integrity for CCS under the CDM. The process proposed is based on the dynamic modeling exercise of CO_2 sources, potential CO_2 seepage pathways and environment and organism receptors of potential CO_2 seepages that are all part of the site characterization and selection and risk assessment processes as well as monitoring scheme design. The EIA would need to include also this process: a site performance assessment and a risk-based assessment of the potential environmental impacts covering analysis of possible CO_2 pathways and receptors. According to the proposal, the environmental, health and safety impact assessment would also include the following elements: a commitment to remediate any in situ local damages caused by seepage and potential seepage events, a commitment to remediate any global impacts of seepage through purchase of offsets or other mechanism, and a commitment to continue monitoring post crediting until liability might be transferred.

G. Market Issues

151. Several submissions reflected in the Second Synthesis Report expressed concerns over possible impacts on the carbon market that could arise from including CCS as a CDM project activity. These concerns are divided into four main sections: carbon market impacts, financing CCS projects, the impact on of other technologies and equitable distribution of CDM projects. These issues are addressed here below.

Carbon Market Impacts

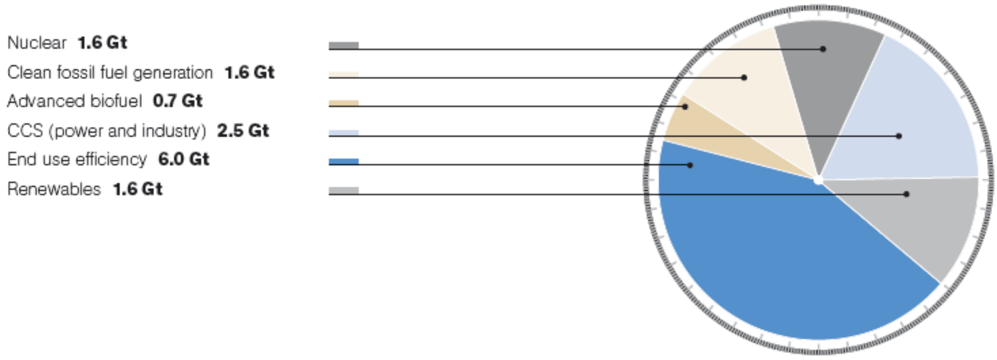
152. The **Second Synthesis Report reflects concerns over possible impacts on the carbon market that could arise from including CCS as a CDM project activity:** There are several components to these concerns: (a) the possibility that huge quantities of CERs from CCS projects would be made available to Annex I Parties, which may undermine the carbon market and reduce CER prices; (b) The risk that CCS being eligible as a project activity under the CDM would lower the level of domestic mitigation action by Annex I Parties as it would open up a new source of cheap CERs; (c) That CCS being eligible as a project activity under the CDM would allow coal-fired power plants to operate in Annex I Parties without CCS, whereas similar plants in non-Annex I Parties would be employing CCS. When assessing the “technical potential” for CCS in non-Annex I countries (Table 2), these concerns seem valid, with over 9 $GtCO_2$/yr available for CO_2 capture, and potentially only around 2 $GtCO_2$/yr of CER demand.

153. **Conversely views expressed suggested that such negative impacts could not happen:** It is argued that the possible undermining of the carbon market and reducing CER prices is not well founded. The principal argument is that whilst there is significant technical potential, in reality deployment is constrained to the limited subset of cases where economic potential can be achieved at prevailing CER prices. To date, prices for CERs have not reached the level needed to finance a significant range of possible CCS project categories, and there is therefore no danger of early CCS projects undermining the CER market. Only “early opportunity” projects will come to market in the early years, but these projects can provide a valuable early contribution to technology transfer. Further, long project lead times, and the rate of CDM approvals will limit the number of projects that can be approved and come into operation before 2012. In the longer term, however, greater CO_2 cuts will be needed and CCS projects will compete with other mitigation options where they are cost-effective.

154. Techno-economic modeling studies are able to provide an insight into CCS deployment; the IPCC in its IPCC SR, considered that the global economic potential of CCS would amount to 220 to 2

200 $GtCO_2$ cumulatively[72]. This corresponds to between 15 to 55% of the cumulative mitigation effort worldwide to 2100 for achieving stabilization of atmospheric concentration of greenhouse gases of between 450 and 750 ppm. This preliminary wide scale of potential CCS was reduced, due to increasing knowledge of the technologies and storage sites, on more realistic bases. More recently[73] [74], the IPCC and UNFCCC has identified CCS as one of the "most promising technologies for rapid reduction of global emissions" and considers CCS, in the portfolio of mitigation technologies, beside energy efficiency, renewables energy...etc. The key technologies of overall emission reductions by technology under the mitigation scenario in 2030 are end-use efficiency (6.0 Gt CO_2 eq.), CCS in power and industry sectors (2.5 Gt CO_2 eq.), renewables (1.6 Gt CO_2 eq.), nuclear energy (1.6 $GtCO_2$ eq.), large hydropower (1.6 $GtCO_2$ eq.) and biofuels (0.7 $GtCO_2$ eq.).

Figure 2: Overall emission reductions by technology under the mitigation scenario in 2030, in Gt CO_2 eq.



Source: UNFCCC, Investment and Financial Flows to Address Climate Change, 2007

155. A study published in November 2008[75] provided an estimate of the market effect of the inclusion of CCS in the CDM. The study integrated previous assessments in several ways: firstly, a detailed bottom-up assessment of CO_2 emissions from natural gas processing (NGP) operations was undertaken; second, an assessment of the potential of other CCS "early opportunity" projects was considered, covering sectors such as ammonia, ethanol, and fertilizer production. Other industrial activities such as oil refineries and cement kilns were also assessed, although these present more challenges for CCS application than the other mentioned. Thirdly cost estimates for different types of CCS applications across these sectors have been compiled. These estimates were then compared with published estimates of emission reduction potentials for other possible candidate CDM abatement options, such as renewable energy, energy efficiency, waste to energy and forestry-based projects. This was used to provide a basis for assessing market effects by comparing cost-ordered marginal abatement costs on a portfolio basis with and without CCS. Included in this portfolio assessment were assumptions for realistic deployment

[72] IPCC Special Report on Carbon Capture and Storage (2005). Summary for Policy Makers, p. 12.
[73] OPEC's 4th International Seminar on Petroleum, Vienna, 19 March 2009, Yvo de Boer UNFCCC.
[74] UNFCCC, Investment and Financial Flows to Address Climate Change, 2007.
[75] IEA GHG R&D Programme. Carbon Dioxide Capture and Storage in the Clean Development Mechanism: Assessing market effects of inclusion; 2008/13, November 2008.

scenario factors for CCS (eg time to develop different project types) and the other technologies. Assessments were made for two periods: 2012 and 2020.

156. The study concluded that over the Kyoto Commitment period:

(a) No CCS would be deployed before 2012 at current estimate of CER supply and demand (of around 360 MCERs per year to 2012).

(b) "Early opportunity" CCS as CDM project activities has a total **technical potential** that could apply CCS <u>in 2012</u> of around 1.24 $GtCO_2$ (219 $MtCO_2$ in natural gas processing and 1020 $MtCO_2$ in other sectors). A portfolio of other candidates CDM abatement options suggested that around 2.3 $GtCO_2$ abatement potential is available in these sectors in 2012. (thus CCS could constitute up to 35% of the total supply of potential abatement options)

(c) The research suggests CCS would only become cost competitive with other CDM candidate options at the margin if demand exceeds about 520 MCERs per year to 2012, based on the cost order of different abatement options, where the first CCS options are at 520 $MtCo_2$ on an marginal abatement cost curve). However, the analysis allows interpretation from a price perspective, and on the basis of CER price estimation, (at $13-14 per CER), CCS could contribute between 0-63 $MtCO_2$ of abatement potential by 2012 (i.e. up to 63 $MtCO_2$ abatement potential from CCS sits below this cost level on the same marginal abatement cost curve). This would be equal to around 0-16 percent of total CER supply at the estimated level of CER demand to 2012. This compares to the current 27 percent of CDM market share occupied by industrial gases (HFC-23, N_2O and PFC destruction; 132.6 MCERs per year) and 18 percent from projects that reduce methane emissions (94.5 MCERs per year).

157. With respect to the period up to 2020 and taking into account natural gas processing, the cement sector and the power sector the **technical potential** of CCS is of 1.45 $GtCO_2$. A portfolio of other candidates CDM abatement options suggested that around 3.7 $GtCO_2$ abatement potential is available in these sectors in 2020 (i.e. CCS constitutes 28% of the total potential supply of abatement options to 2020). For 2020, the analysis suggests, assuming an annual demand of 2,100 MCERs in 2020, that CCS would be deployed under the CDM, with total levels in the range 117-314 $MtCO_2$ per year. This would represent between 6-9 percent of total CER supply."[76]

158. Another analysis, presented in the updated UNFCCC technical paper on "Investment and financial flows to address climate change"[77], estimates that the 2020 overall mitigation potential in developing countries is approximately 7 Gt CO_2eq. This estimate takes into account technologies currently eligible under the CDM as well as other types of Agriculture, Forestry & Land Use (AFOLU) not currently eligible with the CDM, Reduced Deforestation and CCS. Most of this global potential is available at a cost of less than USD 25 per t CO_2 eq[78] (cf. Figure 3 Marginal abatement cost curves for developing countries in 2020). The projected emission reduction potential with CCS technologies shows it is a smaller option. The estimated mitigation potential in developing countries from all CCS

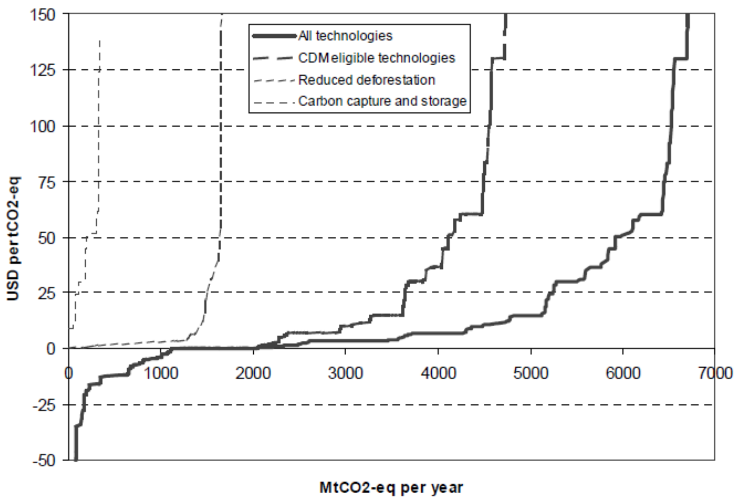
[76] IEA GHG TR2008/13 27.

[77] FCCC/TP/2008/7 Investment and financial flows to address climate change. November 2008.

[78] FCCC/TP/2008/7 Investment and financial flows to address climate change. November 2008.

applications in 2020 is about 350 $MtCO_2$, mostly at costs over 25 USD per t CO_2eq (cf. Figure 3 Marginal abatement cost curves for developing countries in 2020).

Figure 3 Marginal abatement cost curves for developing countries in 2020



Source : FCCC/TP/2008/7

159. The projected emission reduction potential in developing countries appears to be larger than the estimated demand for emission reduction credits in 2020 by developed countries[79]. However the demand for emission reduction credits after 2012 is difficult to estimate because it will be influenced by the outcome of the ongoing negotiations on the Post-Kyoto commitments. But it can be noted that several analysts have produced estimates of the international carbon market in 2020. These estimates of the potential demand for emission reduction credits in 2020 range from 500 to 1 700 Mt CO_2 eq. (cf. Table 3 Estimates of the potential demand for emission reduction credits in 2020). The low end of the range is roughly the same size of the current market (400-600 $MtCO_2eq./y$). The upper range predicts a market two to three times larger.

Table 3 Estimates of the potential demand for emission reduction credits in 2020

Source of estimate	Estimated potential demand
New Carbon Finance[a]	Two or three times the level of demand in 2008 (equating to 1 000–1 500 Mt CO_2 eq)
IDEACarbon[b]	500–1 200 Mt CO_2 eq
Point Carbon[c]	1 700 Mt CO_2 eq
Barclays Capital[d]	600–1 100 Mt CO_2 eq

[a] New Carbon Finance. 2008. "With an international agreement on climate change, the carbon market could be two to three times as large as today." Press release, 28 January 2008.
[b] IDEACarbon. 2008. "The long-term potential of the carbon market." Press release, 29 February 2008.
[c] Point Carbon. 2008. Carbon market transactions: dominated by financials?, *Carbon Market Analyst* (21 May 2008).
[d] Barclays Capital. 2008. So long to the longs. *Monthly Carbon Standard* (June 2008). This is the (annualized) estimate of the maximum potential demand.

[79] FCCC/TP/2008/7

Source: From FCCC/TP/2008/7

160. On the supply side of carbon market, the latest update of the CDM Pipelines [80] suggests that before the end of 2012, 1 278 Million CERs could be issued (or 256 MCERs in each of the 5 years) for coming CDM projects (Table 4 Projections for Issued CERs until the end of 2012, for issuance in the period 2013-2020). Furthermore, after 2012 and until the end of projects crediting period, or until the end of 2020, the CERs issued from existing projects (plus the total issuance in the period 2013-2020) is expected to be 5 525 MCERs or 691 MCERs/year in each of the nine years.

Table 4 Projections for Issued CERs until the end of 2012, for issuance in the period 2013-2020

	Expected 2008-12	**Available 2008-12**	**Available 2013-20**
CER's	Million CERs		
2012 CER's expected from existing projects in validation stage	1018	151	686
2012 CER's expected from projects requesting registration	107	40	59
2012 CER's expected from registered projects	1656	759	546
Total amount of CERs expected from future projects until 2012	972	12	735
Total amount of CERs from existing projects produced after 2012			3499
Total amount of CERs issued	**317**	**1278**	**5525**
Share Of Proceeds (SOP) for the Adaptation Fund	6,3	26	111
Annual amount available		256	691

Source : UNEP RISOE CENTER – August 2009 [81]

161. The economic, technological and institutional barriers to realizing the technical potential for CCS, coupled to the fact that CCS does not appear cost competitive with other CDM candidate technologies until demand for CERs exceeds 600 MCERs before 2012, or 1 200 MCERs per year between 2013 and 2020, suggests that concerns over market unbalancing may be unwarranted.

Financing CCS Projects

162. **In the First and Second Synthesis Reports, some Parties and organizations argue for financing CCS projects using the CDM:** Different arguments put forward are: CCS is a technology designed to reduce atmospheric CO_2 emissions and as such needs incentives; costs of industrial activities in which CCS is used are higher than those of equivalent non-CCS industrial operations; the cost of avoiding CO_2 emission may not be low enough to encourage CCS projects, as this will be dependent on the future carbon price, which in turn is dependent on future commitments; CDM could be an appropriate means to provide sufficient incentives to catalyze funds for a moderate number of early demonstration projects in developing countries. In turn the deployment of early opportunities could: provide valuable learning-by-doing effects for wider deployment of CCS in the medium term; assist in gaining public acceptance of CCS technology and demonstrate the benefits to civil society; the conclusions of the IPCC SR support the view that developing early opportunity projects is a vital part of the development and diffusion process for CCS.

163. **In contrast, some Parties and organization argue against financing CCS projects using the CDM:** Their arguments are: because of the high costs of CCS projects, they are not a cost-effective

[80] UNEP RISOE CENTER – August 2009.

[81] http://www.cdmpipeline.org/overview.htm.

mitigation option; CDM revenues should be used to promote clean and renewable technologies; the CDM was not conceived for giving subsidies to fossil production with CCS; several companies already have considerable know-how and investments in CCS technology; the end of a CCS project is not the end of the costs, implying that additional expenditure is required post-closure for monitoring and other after-care activities.

164. Currently there are five important drivers for deployment of emerging CCS projects worldwide[82]:

- CO_2-Enhanced Hydrocarbon Recovery (EHR) (see the Technical section of this report for an explanation);

- Gas disposal: As in Canada, where CO_2 is co-injected as a by-product with H_2S; CO_2 storage is an incidental benefit of these activities;

- Tax avoidance: As in hydrocarbon production operations on the Norwegian continental shelf (at Sleipner) to avoid the Norwegian CO_2 Discharge Tax (around €40 per tonne CO_2 emitted).

- License to operate: A CCS project (Gorgon in Australia) would potentially be deployed as part of the field development license conditions, albeit with sufficient forms of incentives;

- Research and demonstration: Small-scale CCS projects (e.g. Lacq, Frio Brine; Ketsin, RECOPOL) have been deployed for research and demonstration purposes.

165. In practice, with the exception of these conditions, the only reason for CCS project deployment in non-Annex I countries will be the generation of CERs via the CDM[83] - provided that the CER value may cover the whole cost of the CCS projects[84].

166. The "early opportunity" projects have an abatement costs across the sectors in the range \$18-138 per tCO_2 abated, the lowest being for natural gas processing and the highest costs in cement production[85] (Cf. Table 6 Data for CCS MACs in 2012 and 2020).

167. In 2020, abatement cost estimates are also assumed to remain the same in all sectors, with the exception of natural gas processing, for which costs reduce to \$14 per tCO_2 abated. As there are no additional capture costs, natural gas processing CCS projects will have lower costs and the CDM CERs

[82] from: ERM – Carbon Dioxide Capture and Storage in the Clean Development Mechanism, Report Number: 2007/TR2, April 2007, IEA GHG Program.
[83] coupled with the good will of the project developer to act responsibly toward the environment.
[84] Note that for gas processing in high CO_2 fields, CO_2 capture will be an integral part of the project with or without CO_2 storage i.e. the CO_2 would be captured and vented in order to meet LNG feed quality or pipeline specifications.
[85] Carbon Dioxide Capture and Storage in the Clean Development Mechanism: Assessing Market Effect of Inclusion" IEA GHG R&D Programme Technical Study, RN:2008/13, November 2008.

prices may be sufficient to incentivise some projects[86] (Cf. Table 6 Data for CCS MACs in 2012 and 2020). .

Table 6 Data for CCS MACs in 2012 and 2020

Project type	2012 CER tech. potential (Mt/year)	2012 Av. abate cost ($/tCO$_2$)	2020 CER tech. potential (Mt/year)	2020 Av. abate cost ($/tCO$_2$)
NGP	219.2	$17.6	312.9	$14.2
Ammonia	97.0	$62.2	97.0	$62.2
Fertliser	97.0	$92.1	11.6	$92.1
Ethanol	13.7	$103.7	13.7	$103.1
Refineries	292.3	$114.7	292.3	$114.7
Hydrogen	6.0	$114.9	6.0	$114.9
Cement	600.1	$138.4	600.1	$138.4
Coal power	0.0	n/a	93.0	$36.0
Gas power	0.0	n/a	28.0	$48.0
TOTAL	1,239.9	-	1,454.7	-

Source : "Carbon Dioxide Capture and Storage in the Clean Development Mechanism: Assessing Market Effect of Inclusion" IEA GHG R&D Programme Technical Study, RN:2008/13, November 2008

Effects on Financing for Other Technologies

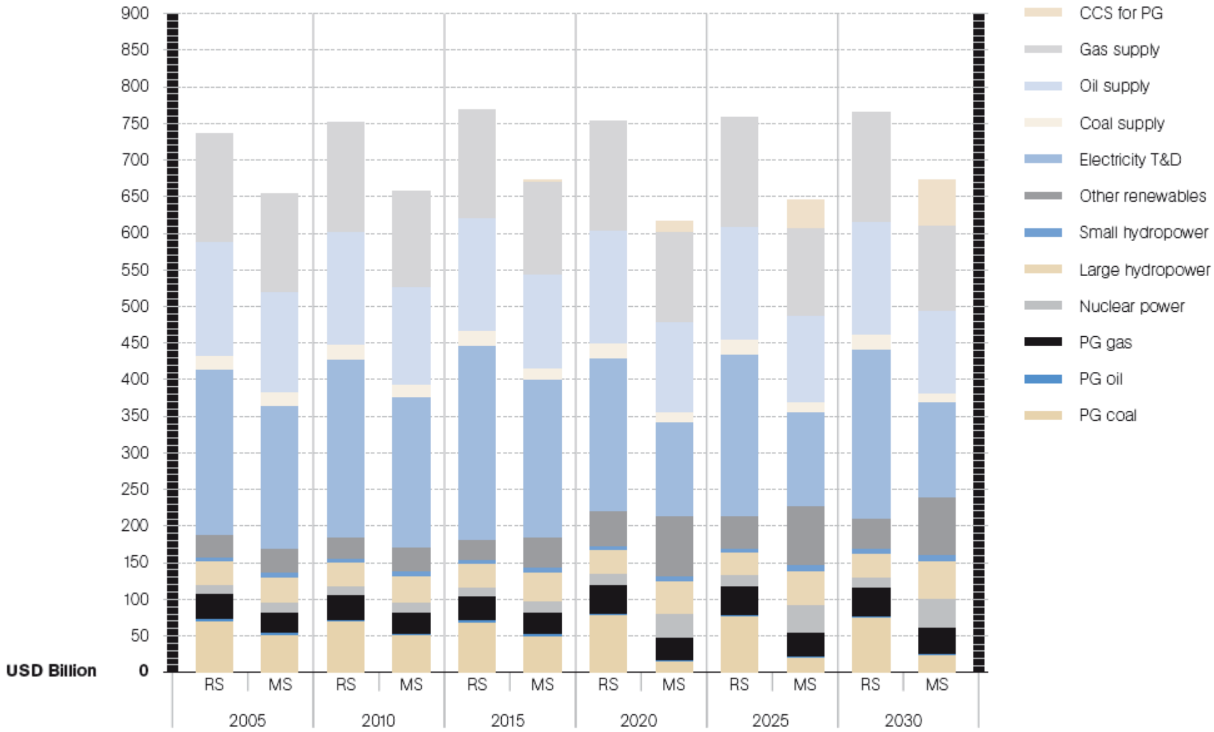
168. In the Second Synthesis Report, some Parties and organizations argue that CCS would postpone, “crowd out” and/or undermine the **availability of funding for other mitigation technologies** such as energy efficiency and renewable energy. These submissions concluded that the CDM should be focused on investing scarce resources in developing countries in energy efficiency and renewable energy projects, including access to clean, reliable and affordable energy.

169. On the other hand it is argued that while renewable energy sources can offer large emissions savings and contribute to energy security goals, they often present only an intermittent power supply, and the requirement for baseload power will limit their deployment. It suggested that CCS offers the only realistic option to address emissions from a range of industrial processes, such as cement production or natural gas processing, that CCS is not a replacement for other options and indeed can complement renewable energy technologies.

170. The UNFCCC study estimates[87] **global investment** in energy supply infrastructure under the mitigation scenario is projected to be USD 695 billion in 2030 worldwide (cf. Figure 4). Power supply requires more than USD 432 billion of investment under the mitigation scenario.

[86] Carbon Dioxide Capture and Storage in the Clean Development Mechanism: Assessing Market Effects of Inclusion. IEA GHG R&D Programme Technical Study 2008/13. November 2008.
[87] UNFCCC, Investment and Financial Flows to address climate change, 2007, §13.

Figure 4 Investment in energy supply needed under the reference (RS) and mitigation scenarios (MS), 2005-2030



Abbreviations: CCS = carbon dioxide capture and storage; PG = power generation; MS = mitigation scenario; RS = reference scenario; T&D = transmission and distribution.

Source : UNFCCC, Investment and Financial Flows to address Climate Change", 2007.

171. The UNFCCC study estimates[88] that global **additional** investment and financial flows of USD 200-210 billion will be necessary in 2030 to return global greenhouse gas emission to current level (26 Gt CO_2). **The worldwide additional investment in CCS in 2030 under the mitigation scenario is over USD 75 billion, of which over USD 63 billion is for power plants**. For industry only, additional investment and financial flows are estimated at about USD 36 billion (see Table 7: Additional investment flows needed under the mitigation scenario in 2030 in the industrial sector (millions of USD). More than half of this additional investment is for energy efficiency (USD 19.5 billion), **one third for installation of CCS (USD 14.1 billion) – from which around USD 11 billion in developing countries** - and the rest for reduction of non-CO_2 gases.

172. Investment and financial flows for mitigation in developing countries are likely to be particularly cost-effective. While investment flows in non-Annex I Parties are estimated at about 46% of the total

[88] UNFCCC, Investment and Financial Flows to address climate change, 2007, §13.

needed in 2030, the emission reductions achieved by the countries amount to 68% of the global emission reductions[89].

Table 7: Additional investment flows needed under the mitigation scenario in 2030 in the industrial sector (millions of USD)

Country/region	Energy-related investment	CH_4 reduction	N_2O reduction	High GWP GHG reduction	CCS	Total
World	19,500	2,028	9	4	14,125	35,665
OECD	11,500	487	5	2	2,052	14,047
OECD North America	5,115	316	2	1	626	6,059
United States	3,899	125	2	1	561	4,587
Canada	750	23	0	0	49	823
Mexico	465	168	0	0	16	649
OECD Pacific	2,340	70	0	1	798	3,209
Japan	1,194	2	0	0	550	1,747
Korea	822	8	0	0	177	1,008
Australia and New Zealand	324	59	0	0	70	453
OECD Europe	4,045	102	3	0	629	4,779
Transition economies	1,061	369	0	0	804	2,234
Russia	596	157	0	0	260	1,013
Other EIT	465	212	0	0	544	1,222
Developing Countries	6,939	1,171	3	2	11,269	19,384
Developing Asia	4,887	691	2	1	10,691	16,273
China	3,157	421	2	1	8,621	12,202
India	727	154	0	0	982	1,863
Indonesia	202	41	0	0	214	457
Other Developing Asia	802	75	0	0	875	1,751
Latin America	798	125	1	0	278	1,202
Brazil	393	21	0	0	199	614
Other Latin America	405	104	0	0	80	588
Africa	410	217	0	0	275	902
Middle East	844	139	0	0	24	1,008

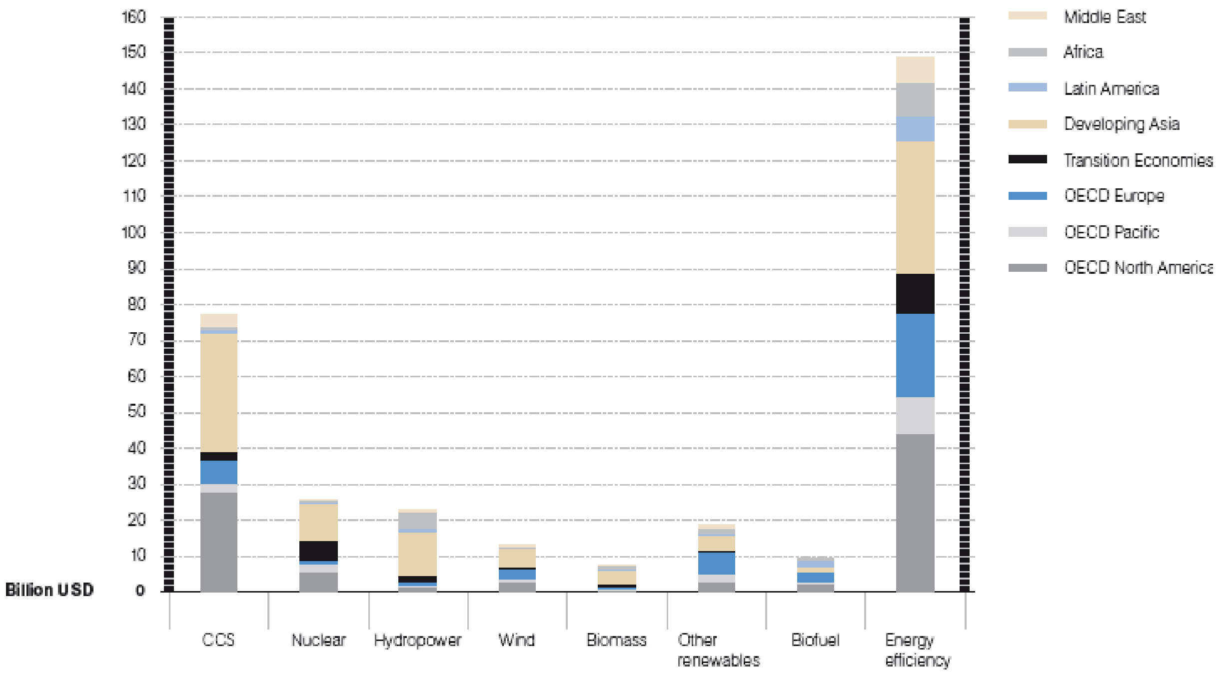
Abbreviations: CCS = carbon dioxide capture and storage, EIT = Economies in transition, GHG = Greenhouse gas, GWP = Global warming potential, OECD = Organisation for Economic Co-operation and Development, CH_4 = methane, N_2O = nitrous oxide.

Source : UNFCCC, Investment and Financial Flows to address Climate Change", 2007.

173. The annual investment by technology by region in 2030 in mitigation scenario shows a substantial share will be invested in developing countries (Figure 5 Annual additional investment by technology and by region under the mitigation scenario in 2030). This suggests developing countries would play an important role in R&D and deployment of technologies.

[89] UNFCCC, Investment and Financial Flows to Address Climate Change, 2007.

Figure 5 Annual additional investment by technology and by region under the mitigation scenario in 2030



Source : UNFCCC, Investment and Financial Flows to address Climate Change", 2007.

Equitable Distribution of CDM Projects

174. Several submissions suggested that including CCS in the CDM would further **increase the inequality of distribution of CDM projects**, as its application would be limited to large emission reduction projects in a few non-Annex I Parties that have major coal-fired power generation and/or oil and gas export operations.

175. However, a number of submissions also suggested that this should not be a reason to exclude CCS as a CDM project activity, for the following reasons: CCS should be a technology that is implemented wherever it is needed; for some countries, protecting their bio-sequestration capability may be the largest contribution they can make to combating climate change, but for other countries with less extensive bio-production, their potential to store large volumes of CO_2 through CCS may be the most promising option.

176. Moreover, results from quantitative analysis presented in an IEA study[90] suggest that CCS actually could assist with decreasing the inequality of distribution of CDM projects, as potential likely countries for early CCS projects not those with a large share of the current project pipeline, but countries such as Indonesia, Malaysia, Thailand, Algeria, Saudi Arabia, and Qatar.

[90] Carbon Dioxide Capture and Storage in the Clean Development Mechanism: Assessing Market Effect of Inclusion" IEA GHG R&D Programme Technical Study, RN:2008/13, November 2008.

177. A UNFCCC report[91] highlights the limitations with respect to knowledge concerning large-scale deployment of CCS, but states that the technology is assumed to play a key role in for the mitigation of carbon emissions. The geographic distribution of CCS projects adopted for the analysis presented in the study is based on limited information regarding storage potential and growth of fuel-fired power plants.

Permanence and Market Implications

178. The permanence issue of CO_2 storage in the context of CCS as CDM project activities[92] poses challenges for accounting. If seepage occurs during a crediting period, these emissions can be monitored and reported as Project Emissions. If seepage from the storage reservoir occurs after the crediting period, liability for these emissions needs to be managed to maintain the environmental integrity of the CDM over the longer-term.

179. In that aim, three liability provisions to handle permanence storage have been proposed: [93]

(a) Creating longer-term liability for project developers/operators to buy GHG compliance units such as CERs in the event of seepage emissions as part of a CCS project approval process. The advantage of this proposition is CERs from CCS projects would be fungible with other commodities in the GHG market.

(b) Flagging CCS-specific CERs or issuing temporary CERs which would be cancelled and require placement, pro rata, in the event that seepage occurred. This in consequence would pass liability for seepage emissions on to the buyer of the CERs; flagged or temporary CERs will affect their fungibility in the GHG markets.

(c) Applying a default or discounted factor to account for future seepage emissions so that either a portion of CERs are not issued, a portion are set aside in a credit reserve, or a portion of the revenue from CERs sales is set aside in a contingency fund...etc. This could cap liability for all actors in the market at the chosen default or discount rate. But it is a complex and contentious process as there is no scientific basis for setting such factors. Furthermore, it is unclear how any seepage emissions greater than discount/default factor applied would be handled.

180. The current carbon market has not assimilated the temporary CERs (t-CERs and l-CERs) that are generated from Afforestation and Reforestation CDM project activities and the demand is very low. This does not speak in favor of a solution based on temporary credits. Moreover, as said in the section on Legal Issues in this report, relying on temporary or discounted CERs to allow for potential seepage at some point in time would reduce or remove the incentive to manage and ensure long-term integrity that comes from the penalty of having to surrender CERs equal to the seepage amounts.

---

[91] UNFCCC, Investment and Financial Flows to address Climate Change", 2007.

[92] A definition was proposed in the Report number 2007/TR2, April 2007, "ERM – Carbon Dioxide Capture and Storage in the clean Development Mechanism", IEA-GHG : ...the ability of a CDM project activity to achieve long term reduction in emissions of greenhouse gases to the atmosphere below levels that would occur in the absence of the project activity".

[93] Report number 2007/TR2, April 2007, "ERM – Carbon Dioxide Capture and Storage in the clean Development Mechanism", IEA-GHG .

181. It is recommended that the structure of liability provisions needs to be practical and predictable for both project developers and the international GHG market. It is also important to note that in absence of certainty over future CER prices, to cap the residual liability on the requirement to purchase any CERs in the event of seepage emissions. Without a cap on liability, investment decision-making would be impossible as the project would involve the taking-on of unquantifiable contingent liabilities, which would be commercially unworkable.

H. Other Funding and Technology Transfer Alternatives for CCS

182. CCS reduces energy efficiency and adds capital and operational costs. Investment in CCS will therefore in principle only occur if there are sufficient financial incentives and/or regulatory mandates (with the exception of Enhanced Oil Recovery). Investment barriers can be partially overcome by for example tax credits. But even then technology inertia and the lack of sufficient business incentives may mean that there will be a need for further significant government and industrial financial support to facilitate CCS.

183. Government assistance is particularly needed at the early stages. Public-private partnerships have been formed to address financing gaps, but several projects have been cancelled or scaled back due to difficulties in locating sufficient resources.

184. Several industrialised countries have initiated CCS Demonstration efforts including Australia, the EU, Norway, the United Kingdom and the United States.

185. Given the large sums of money that will be needed to adequately demonstrate CCS, the climate change benefits, and the need for the international transfer of knowledge and technology, international financial institutions have an important role to play in financing CCS.

186. A number of initiatives to facilitate international transfer of knowledge and technology related to CCS that have been taken are outlined below:

187. **ADB carbon storage fund:** An Australian-backed fund will identify Asian sites for carbon capture and storage (CCS) projects. The Australian government has pledged A$21.5 million (US$17.6 million) for the venture which will be partnered by the Asian Development Bank. It will focus on CCS projects in China, India, Indonesia and Vietnam. The Australian funding will come from the Global Carbon Capture and Storage Institute.

188. **The Clean Technology fund – World Bank:** The World Bank Group, in consultation with the regional development banks and developed and developing countries, and other development partners has established a Clean Technology Fund (CTF). The CTF will seek to demonstrate how financial and other incentives can be scaled-up to accelerate deployment, diffusion and transfer of low-carbon technologies. In the power sector, the CTF may promote a development towards readiness for implementation of carbon capture and storage.

189. **The European Investement Bank (EIB):** The EIB has announced that it has dedicated EUR 10 billion to support risk sharing in CCS projects in Europe, as well as another EUR 3 billion to finance CCS projects outside the EU.

190. **EU's NZEC project:** The project is aimed at CCS on coal power generation in China. It has nearly completed Phase 1 feasibility studies, and has secured funding for phase two, which will go into

more detailed studies and design for a CCS demonstration in China. This capacity building and technology transfer funded by Annex 1 countries will result in one demonstration in China by 2020, while more demonstrations covering different CCS options for China are required.

191. The Global Environment Facility (GEF), on the other hand, has considered CCS, but recognises that it cannot fund at scale required for CCS projects.

192. Initiatives such as the ones mentioned above will be particularly important for the demonstration of CCS in the power sector of developing countries as financial incentives from market-based mechanisms alone will be insufficient in the near to medium term to stimulate CCS investments in this sector.

193. It is worth noting that funding alternatives such as the ones addressed here necessitate the same care in selecting and operating CO_2 storage sites, so as to secure permanence of storage, as would be required for CCS project activities under the CDM.

194. The nature of financing (e.g. level and type of support in terms of both capital (investment) and operating (costs) support) should determine whether such projects might also be eligible for carbon market finance, based on the principle of additionality adopted for other CDM project activities.

I. Recommendations and Institutional Implications for the CDM

195. Bullets are Recommendations (•) and Institutional Implications (o)

No requirement for further guidance by the Board

- Regulation of CCS in the host country for CCS project activities, with an appropriate regulatory body to administer it, is highly important. An objective of any DOE validating a CCS CDM project activity would be to assess whether there is a regulatory framework that could be considered sufficient in place in the host country to control the project, and whether the appropriate regulatory approval has been or can be given to the particular project.

- Given the range of options open, and the limited number of projects expected in developing countries during the first and a second commitment period, at this early stage, if CCS were allowed in the CDM and assuming long-term liability transfer to the host country, host countries should be allowed to choose their liability transfer and funding mechanisms, so as to allow 'learning'. DOEs and the Board would need to be satisfied with the outline arrangements to undertake liability transfer, which should be detailed in advance in the post-closure plan in the PDD, and to give their approval or not.

- The Environmental Impact Assessment carried out for each potential CCS project under the CDM, albeit governed by national regulations, should be based on the risk assessment procedure that should be outlined in any CCS CDM methodology and PDD.

Requirement for guidance by the Board

- Thorough understanding of the permanence issue requires advanced expertise in complex technical areas. If CCS is considered eligible under the CDM, the Board should establish a CCS Working Group. The Working Group shall have the mandate to support the Board on technical issues related to the permanence of CO_2 storage in geological formations, including the accreditation of DOEs to validate CCS projects, supporting the Board in developing criteria for the assessment of CO_2 storage site selection and approval, and preparing recommendations on technical matters related to the permanence of CO_2 storage in submitted proposals for new baseline and monitoring methodologies.

  - The Board to establish a CCS Working Group.

- Any CCS project activities approved under the CDM should be located to secure sites and operated according to best practice. If CCS is considered eligible under the CDM, the Board should develop criteria for the assessment of site selection and approval, including risk assessment, drawing on the existing knowledge base. For any proposed geological CCS CDM project activities, the site characterisation and selection process should be fully described.

  - The Board to develop criteria for the assessment of site selection and approval.

- Any CCS project activities approved under the CDM should employ proper risk management and operation and monitoring of reservoirs and should feature appropriate remediation programmes to be employed in the event seepage should occur. For any proposed CCS CDM project activities all these aspects should be fully described. Seepage remediation options should be described in connection with an analysis of the most likely seepage scenarios in implementing any methodologies.

  - The Board to issue general guidance with respect to this requirement for New Methodologies.

- DOEs wishing to validate CCS projects would have to be accredited with this expertise.

  - The Board to introduce new Sectoral Scope on CCS, for DOEs to be accredited under.

- The validation of the site characterisation and selection would require a DOE with appropriate CCS expertise.

- The validation of the remediation plan would require a DOE with appropriate CCS expertise.

- The assessment of a monitoring programme (in the PDD) would require a DOE with appropriate CCS expertise.

  - The Board to accredit DOEs for validation of CCS CDM projects.

- New Monitoring Methodologies would need to be created for any CCS project activities under the CDM, and all CCS Monitoring Methodologies should follow the same four objectives of performance monitoring, seepage detection, seepage quantification and seepage impact assessment, with the latter two objectives only being triggered if leakage is detected or suspected from the monitoring results of the first two objectives.

  - The Board to issue general guidance with respect to this requirement for New Monitoring Methodologies.

- Monitoring Methodologies should set overall objectives while leaving flexibility in the monitoring programme details, so as to allow the most appropriate monitoring techniques to be selected given specific geological situations. The First UNFCCC Synthesis Report provides a listing of the elements to be included in a monitoring programme, derived from the IPCC GHG Guidelines. It is recommended that these should be followed in any CCS CDM Monitoring Methodologies. For each project, the monitoring programme and techniques should be derived from the site characterisation and modelling for the particular site, and fully described in the PDD so that they can be assessed. Within the context of the subsurface element of a CCS CDM methodology/ies there should be a periodic requirement for the revised modelling results to be re-assessed by a DOE.
    - The Board to issue general guidance with respect to this requirement for New Monitoring Methodologies.
- For CO_2 storage site seepage, any uncertainty in quantification needs to be addressed to avoid underestimating actual seepage emissions. Any new Monitoring Methodologies for CCS in the CDM should use the same factors as in the EU regulation so as to avoid underestimating seepage amounts.
    - The Board to issue general guidance with respect to this requirement for New Monitoring Methodologies.
- The Board may consider requirements for monitoring post closure and post CDM crediting period for any proposed geological CCS CDM methodologies regardless of whether the storage site is in the responsibility of the operator or if the responsibility has been transferred to a state authority.
    - The Board to issue general guidance with respect to this requirement for New Monitoring Methodologies.
- The project boundary should comprise both above ground and below ground components, including a larger volume than just the storage reservoir so as to include potential secondary containment formations. This larger volume, referred to as a ‘storage complex’, being the storage site and surrounding geological domains which can have an effect on overall storage integrity and security. Using a good site characterisation and modelling, together with inclusion within the boundary of a storage complex, could be considered sufficient for projects to be able to proceed in the CDM. In the event that CO_2 does move out of the project spatial boundary, the PDD should be revised and reassessed by the DOE and Board, with the option of changing the spatial boundary as the most important thing is to ensure all potential seepage locations are included within the project boundary.
    - The Board to issue general guidance with respect to this requirement for New Methodologies.
- The project temporal boundary should include all of the above up to the end of a monitoring period undertaken by a responsible entity after liability transfer.
    - The Board to issue general guidance with respect to this requirement for New Methodologies.

- During the crediting period of a CCS project under the CDM, the liability for CO_2 seepage should reside with the operator. The 2006 IPCC Guidelines established the principle that CO_2 transferred to a CO_2 storage site counts as not emitted, which is followed by the revised EU ETS Directive. In the EU ETS system, if there are subsequent seepage emissions from storage, then the storage operator has to surrender emission allowances equivalent to the seepage amount. This principle should be applied for CCS CDM projects also, in the short and long-term.
    - The Board to issue general guidance with respect to this requirement.
- After the CDM project crediting period, there would have to be a means of ensuring the environmental integrity of the CDM is maintained in the event of seepage. The basic requirement should be that CERs (or equivalent at the time) equal to the quantity of seepage CO_2 should be surrendered by an entity responsible for the project to the UNFCCC CDM Registry Account, and the seepage source would be remediated.
    - The Board to develop general guidance with respect to this requirement.
- Due to the additional legal implications for cross-border storage, CCS projects in the first and a second commitment period would be limited to take place within national boundaries and with no risk of migration across national boundaries.
    - The Board to issue general guidance with respect to this requirement.
- If CCS is considered eligible under the CDM no waste or other matter may be added to a CO_2 stream of a CCS CDM project activity for the purpose of discarding that waste or other matter. Acceptable levels of impurities in CO_2 streams shall be determined based on its potential impacts on transport and storage integrity. Operators of potential CCS projects under the CDM shall prove that their CO_2 streams are sufficiently pure and that they have adequately considered the relationship between CO_2 stream purity and the surrounding cap rock, including environmental and other risks of CO_2 storage.
    - The Board to issue general guidance with respect to this requirement.

Requirement for further clarification by the CMP

- It may take time and resources for a host country to develop regulation of CCS in the host country for CCS project activities, with an appropriate regulatory body to administer it. Support to facilitate such developments may be considered.
    - The CMP to consider how the UNFCCC process could support the development of regulatory capacity in potential host countries for CCS CDM project activities.

J. Glossary

Adsorption: The uptake of molecules on the surface of a solid or a liquid.

Anthropogenic source: Source which is man-made as opposed to natural.

Aquifer: Geological structure containing water and with significant permeability to allow flow; it is bound by seals.

Baseline (I): With respect to monitoring of geological CO_2 storage: The datum against which change is measured.

Baseline (II): With respect to CDM project activities: The baseline for a CDM project activity is the scenario that reasonably represents the anthropogenic emissions by sources of greenhouse gases (GHG) that would occur in the absence of the proposed project activity. A baseline shall cover emissions from all gases, sectors and source categories listed in Annex A (of the Kyoto Protocol) within the project boundary. A baseline shall be deemed to reasonably represent the anthropogenic emissions by sources that would occur in the absence of the proposed project activity if it is derived using a baseline methodology referred to in paragraphs 37 and 38 of the CDM modalities and procedures.

Basin: A geological region with strata dipping towards a common axis or centre.

Benthic: Pertaining to conditions at depth in bodies of water.

Boundary: In GHG accounting, the separation between accounting units, be they national, organizational, operational, business units or sectors. For CDM project activities the project boundary shall encompass all anthropogenic emissions by sources of greenhouse gases under the control of the project participants that are significant and reasonably attributable to the CDM project activity.

Cap rock: Rock of very low permeability that acts as an upper seal to prevent fluid flow out of a reservoir.

Carbon credit: A convertible and transferable instrument that allows an organization to benefit financially from an emission reduction.

Carbon trading: A market-based approach that allows those with excess emissions to trade that excess for reduced emissions elsewhere.

Carbonate: Natural minerals composed of various anions bonded to a CO_2- cation (e.g. calcite, dolomite, siderite, limestone).

CCS: Carbon dioxide capture and storage

CDM: Clean development mechanism: a Kyoto Protocol mechanism to assist non-Annex 1 countries to contribute to the objectives of the Protocol and help Annex I countries to meet their commitments.

Chemical looping combustion: A process in which combustion of a hydrocarbon fuel is split into separate oxidation and reduction reactions by using a metal oxide as an oxygen carrier between the two reactors.

CO_2 avoided: The difference between CO_2 captured, transmitted and/or stored, and the amount of CO_2 generated by an equivalent system with the same output or level of service without capture, net of the emissions not captured by a system with CO_2 capture.

CO_2 equivalent: A measure used to compare emissions of different greenhouse gases based on their global warming potential.

Continental shelf: The extension of the continental mass beneath the ocean.

Deep saline aquifer: A deep underground rock formation composed of permeable materials and containing highly saline fluids.

Dense phase: A gas compressed to a density approaching that of the liquid.

Depleted: Of a reservoir: one where production is significantly reduced.

EGR: Enhanced gas recovery: the recovery of gas additional to that produced naturally by fluid injection or other means.

EHR: Enhanced hydrocarbon recovery. Collective term for EGR and EOR.

Emission factor: A normalized measure of GHG emissions in terms of activity, e.g., tonnes of GHG emitted per tonne of fuel consumed.

Emissions credit: A commodity giving its holder the right to emit a certain quantity of GHGs (q.v.).

Emissions trading: A trading scheme that allows permits for the release of a specified number of tonnes of a pollutant to be sold and bought.

EOR: Enhanced oil recovery: the recovery of oil additional to that produced naturally by fluid injection or other means.

Fault: In geology, a surface at which strata are no longer continuous, but displaced.

Flue gas: Gases produced by combustion of a fuel that are normally emitted to the atmosphere.

Formation: A body of rock of considerable extent with distinctive characteristics that allow geologists to map, describe, and name it.

Fracture: Any break in rock along which no significant movement has occurred.

Fugitive emission: Any releases of gases or vapours from anthropogenic activities such as the processing or transportation of gas or petroleum.

Gasification: Process by which a carbon-containing solid fuel is transformed into a carbon- and hydrogen-containing gaseous fuel by reaction with air or oxygen and steam.

GHG: Greenhouse gases: carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), hydroflurocarbons (HFCs), perfluorocarbons (PFCs), and sulphur hexafluoride (SF_6).

Injection: The process of using pressure to force fluids down wells.

Injection well: A well in which fluids are injected rather than produced.

***In-situ* mineralization:** A process where minerals are not mined: carbon dioxide is injected in the silicate formation where it reacts with the minerals, forming carbonates and silica.

IPCC: Intergovernmental Panel on Climate Change

Kyoto Protocol: Protocol to the United Nations Framework Convention on Climate Change, which was adopted at Kyoto on 11 December 1997.

Leakage (I): In respect of carbon trading, the change of anthropogenic emissions by sources or removals by sinks which occurs outside the project boundary.

Leakage (II): In the context of CDM projects is defined as the net change of anthropogenic emissions by sources of greenhouse gases (GHG) which occurs outside the project boundary, and which is measurable and attributable to the CDM project activity.

LNG: Liquefied natural gas

London Convention: On the Prevention of Marine Pollution by Dumping of Wastes and Other Matter, which was adopted at London, Mexico City, Moscow and Washington on 29 December 1972.

London Protocol: Protocol to the Convention adopted in London on 2 November 1996 but which had not entered into force at the time of writing.

Low-carbon technology: Technology that provides a service with low emissions of CO_2.

Marginal cost: Additional cost that arises from the expansion of activity. For example, emission reduction by one additional unit.

Membrane: A sheet or block of material that selectively separates the components of a fluid mixture.

Mineral trap: A geological structure in which fluids are retained by the reaction of the fluid to form a stable mineral.

Mitigation: The process of reducing the impact of any failure.

Monitoring: The process of measuring the quantity of carbon dioxide stored and its location.

National Greenhouse Gas Inventory: An inventory of anthropogenic emissions by sources and removals by sinks of greenhouse gases prepared by Parties to the UNFCCC.

Natural analogue: A natural occurrence that mirrors in most essential elements an intended or actual human activity.

OSPAR: Convention for the Protection of the Marine Environment of the North-East Atlantic, which was adopted at Paris on 22 September 1992.

Oxyfuel combustion: Combustion of a fuel with pure oxygen or a mixture of oxygen, water and carbon dioxide.

Permeability: Ability to flow or transmit fluids through a porous solid such as rock.

Pore space: Space between rock or sediment grains that can contain fluids.

Porosity: Measure for the amount of pore space in a rock.

Post-combustion capture: The capture of carbon dioxide after combustion.

Pre-combustion capture: The capture of carbon dioxide following the processing of the fuel before combustion.

Reduction commitment: A commitment by a Party to the Kyoto Protocol to meet its quantified emission limit.

Reservoir: A subsurface body of rock with sufficient porosity and permeability to store and transmit fluids.

Retrofit: A modification of the existing equipment to upgrade and incorporate changes after installation.

Saline formation: Sediment or rock body containing brackish water or brine.

Seabed: Borderline between the free water and the top of the bottom sediment.

Seal: An impermeable rock that forms a barrier above and around a reservoir such that fluids are held in the reservoir.

Seepage: The term used in this document to refer to physical leakage from storage site

Sink: The natural uptake of CO_2 from the atmosphere, typically in soils, forests or the oceans.

Source: Any process, activity or mechanism that releases a greenhouse gas, an aerosol, or a precursor thereof into the atmosphere.

Storage: A process for retaining captured CO_2 so that it does not reach the atmosphere.

Sustainable: Of development, that which is sustainable in ecological, social and economic areas.

Supercritical: At a temperature and pressure above the critical temperature and pressure of the substance concerned. The critical point represents the highest temperature and pressure at which the substance can exist as a vapour and liquid in equilibrium

Trap: A geological structure that physically retains fluids that are lighter than the background fluids, e.g. an inverted cup.

UNFCCC: United Nations Framework Convention on Climate Change, which was adopted at New York on 9 May 1992.

Validation: In the context of CDM (q.v.), the process of the independent evaluation of a project by a designated operational entity on the basis of set requirements.

Verification: The proving, to a standard still to be decided, of the results of monitoring (q.v.). In the context of CDM, the independent review by a designated operational entity of monitored reductions in anthropogenic emissions.