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Implications of carbon dioxide capture and storage for greenhouse gas inventories and accounting

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EXECUTIVE SUMMARY

This chapter addresses how methodologies to estimate and report reduced or avoided greenhouse gas emissions from the main options for CO_2 capture and storage (CCS) systems could be included in national greenhouse gas inventories, and in accounting schemes such as the Kyoto Protocol.

The *IPCC Guidelines* and Good Practice Guidance reports (*GPG2000* and *GPG-LULUCF*) [1]are used in preparing national inventories under the UNFCCC. These guidelines do not specifically address CO_2 capture and storage, but the general framework and concepts could be applied for this purpose. The IPCC guidelines give guidance for reporting on annual emissions by gas and by sector. The amount of CO_2 captured and stored can be measured, and could be reflected in the relevant sectors and categories producing the emissions, or in new categories created specifically for CO_2 capture, transportation and storage in the reporting framework. In the first option, CCS would be treated as a mitigation measure and, for example, power plants with CO_2 capture or use of decarbonized fuels would have lower emissions factors (kgCO_2/kg fuel used) than conventional systems. In the second option, the captured and stored amounts would be reported as removals (sinks) for CO_2. In both options, emissions from fossil fuel use due to the additional energy requirements in the capture, transportation and injection processes would be covered by current methodologies. But under the current framework, they would not be allocated to the CCS system.

Methodologies to estimate, monitor and report physical leakage from storage options would need to be developed. Some additional guidance specific to the systems would need to be given for fugitive emissions from capture, transportation and injection processes. Conceptually, a similar scheme could be used for mineral carbonation and industrial use of CO_2. However, detailed methodologies would need to be developed for the specific processes.

Quantified commitments, emission trading or other similar mechanisms need clear rules and methodologies for accounting for emissions and removals. There are several challenges for the accounting frameworks. Firstly, there is a lack of knowledge about the rate of physical leakage from different storage options including possibilities for accidental releases over a very long time period (issues of permanence and liability). Secondly, there are the implications of the additional energy requirements of the options; and the issues of liability and economic leakage where CO_2 capture and storage crosses the traditional accounting boundaries.

The literature on accounting for the potential impermanence of stored CO_2 focuses on sequestration in the terrestrial biosphere. Although notably different from CCS in oceans or in geological reservoirs (with respect to ownership, the role of management, measurement and monitoring, expected rate of physical leakage; modes of potential physical leakage; and assignment of liability), there are similarities. Accounting approaches, such as discounting, the ton-year approach, and rented or temporary credits, are discussed. Ultimately, political processes will decide the value of temporary storage and allocation of responsibility for stored carbon. Precedents set by international agreements on sequestration in the terrestrial biosphere provide some guidance, but there are important differences that will have to be considered.

9.1 Introduction

CO_2 capture and storage (CCS) can take a variety of forms. This chapter discusses how the main CCS systems as well as mineral carbonation and industrial uses of CO_2, described in the previous chapters could be incorporated into national greenhouse gas inventories and accounting schemes. However, inventory or accounting issues specific to enhanced oil recovery or enhanced coal bed methane are not addressed here.

The inclusion of CCS systems in national greenhouse gas inventories is discussed in Section 9.2 (Greenhouse gas inventories). The section gives an overview of the existing framework, the main concepts and methodologies used in preparing and reporting national greenhouse gas emissions and removals with the aim of identifying inventory categories for reporting CCS systems. In addition, areas are identified where existing methodologies could be used to include these systems in the inventories, and areas where new methodologies (including emission/removal factors and uncertainty estimates) would need to be developed. Treatment of CCS in corporate or company reporting is beyond the scope of the chapter.

Issues related to accounting[2] under the Kyoto Protocol; or under other similar accounting schemes that would limit emissions, provide credits for emission reductions, or encourage emissions trading; are addressed in Section 9.3 (Accounting issues). The section addresses issues that could warrant special rules and modalities in accounting schemes because of specific features of CCS systems, such as permanence of CO_2 storage and liability issues related to transportation and storage in international territories and across national borders. Specific consideration is also given to CCS systems in relation to the mechanisms of the Kyoto Protocol (Emission Trading, Joint Implementation and the Clean Development Mechanism).

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[1] Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories (IPCC 1997) – abbreviated as IPCC Guidelines in this chapter; IPCC Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories (IPCC 2000) – abbreviated as GPG2000; and IPCC Good Practice Guidance for Land Use, Land-Use Change and Forestry (IPCC 2003) – abbreviated as GPG-LULUCF.

[2] 'Accounting' refers to the rules for comparing emissions and removals as reported with commitments. In this context, 'estimation' is the process of calculating greenhouse gas emissions and removals, and 'reporting' is the process of providing the estimates to the UNFCCC (IPCC 2003).

9.2 National greenhouse gas inventories

Information on pollutant emissions is usually compiled in 'emission inventories'. Emissions are listed according to categories such as pollutants, sectors, and source and compiled per geographic area and time interval. Many different emission inventories have been prepared for different purposes. Among the commitments in the United Nations Framework Convention on Climate Change (UNFCCC, 1992) all Parties, taking into account their common but differentiated responsibilities, and their specific national and regional development priorities, objectives and circumstances, shall: 'Develop, periodically update, publish and make available to the Conference of the Parties, national inventories of anthropogenic emissions by sources and removals by sinks of all greenhouse gases not controlled by the Montreal Protocol, using comparable methodologies to be agreed upon by the Conference of the Parties'.[3]

Industrialized countries (Annex I Parties) are required to report annually and developing countries (non-Annex I Parties) to report on greenhouse gas emissions and removals to the Convention periodically, as part of their National Communications to the UNFCCC. National greenhouse gas inventories are prepared using the methodologies in the *IPCC Guidelines* as complemented by the *GPG2000* and G*PGLULUCF*, or methodologies consistent with these. These inventories should include all anthropogenic greenhouse gas emissions by sources and removals by sinks not covered by the Montreal Protocol. To ensure high quality and accuracy, inventories by Annex I Parties are reviewed by expert review teams coordinated by the UNFCCC Secretariat. The review reports are published on the UNFCCC website[4].

The rules and modalities for accounting are elaborated under the Kyoto Protocol (UNFCCC, 1997) and the Marrakech Accords[5] (UNFCCC, 2002). The Kyoto Protocol specifies emission limitation or reduction commitments by the Annex I Parties for six gases/gas groups: carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), hydrofluorocarbons (HFCs), perfluorocarbons (PFCs) and sulphur hexafluoride (SF_6).

At present, CCS is practiced on a very small scale. CCS projects have not generally been described in the national inventory reports of the countries where they take place. An exception is the Sleipner CCS project, which is included in Norway's inventory report.[6] Norway provides information on the annual captured and stored amounts, as well as on the amounts of CO_2 that escape to the atmosphere during the injection process (amounts have varied from negligible to about 0.8% of the captured amount). The escaping CO_2 emissions are included in the total emissions of Norway. The spread of the CO_2 in the storage reservoir has been monitored by seismic methods. No physical leakage has been detected. An uncertainty estimate has not been performed but it is expected to be done when more information is available from the project's monitoring programme.

The scarce reporting of current CCS projects is due largely to the small number and size of industrial CCS projects in operation, as well as to the lack of clarity in the reporting methodologies.

9.2.1 Revised 1996 IPCC Guidelines and IPCC Good Practice Guidance

The reporting guidelines under the UNFCCC[7], and under the Kyoto Protocol as specified in the Marrakech Accords require Annex I Parties to use the *IPCC Guidelines*[1], as elaborated by the *GPG2000*[1], in estimating and reporting national greenhouse gas inventories. The use of the *GPG-LULUCF*[1] will start in 2005 with a one-year trial period[8]. Non-Annex I Parties also use the *IPCC Guidelines* in their reporting, and use of *GPG2000* and *GPG-LULUCF* reports is encouraged.[9] The main reporting framework (temporal, spatial and sectoral) and the guiding principles of the *IPCC Guidelines* and good practice guidance reports are given in Box 9.1.

The IPCC Guidelines will be revised and updated by early 2006[10]. In the draft outline for the 2006 IPCC Guidelines for National Greenhouse Gas Inventories, CCS is mentioned in a footnote in the Energy Sector: 'It is recognized that CO_2 capture and storage is an important emerging issue in inventory development. The coverage of CO_2 storage in this report will be closely coordinated with progress on IPCC SR on CO_2 capture and storage. CO_2 capture activities will be integrated as appropriate into the methods presented for source categories where it may occur.'

9.2.2 Methodological framework for CO_2 capture and storage systems in national greenhouse gas inventories

The two main options for including CCS in national greenhouse gas inventories have been identified and analysed using the current methodological framework for total chain from capture to storage (geological and ocean storage). These options are:

- Source reduction: To evaluate the CCS systems as mitigation options to reduce emissions to the atmosphere;

[3] Commitment related to the Articles 4.1 (a) and 12.1 (a) of the United Nations Framework Convention of Climate Change (UNFCCC).

[4] http://unfccc.int

[5] The Marrakech Accords refer to the Report of the Conference of the Parties of the UNFCCC on its seventh session (COP7), held in Marrakech 29 October to 10 November 2001.

[6] Norway's inventory report can be found at http://cdr.eionet.eu.int/no/un/UNFCCC/envqh6rog.

[7] FCCC/CP2002/7/Add.2: Annexes to Decision 17/CP.8 Guidelines for the preparation of national communications from Parties not included in Annex I to the Convention and 18/CP.8 Guidelines for the preparation of national communications by Parties included in Annex I to the Convention, part I: UNFCCC reporting guidelines on annual inventories.

[8] FCCC/SBSTA/2003/L.22 and FCCC/SBSTA/2003/L.22/Add.1.

[9] FCCC/CP/2002/7/Add.2.

[10] http://www.ipcc.ch/meet/session21.htm: IPCC XXI/Doc.10.

Box 9.1 Main reporting framework (temporal, spatial and sectoral) and guiding principles of the IPCC Guidelines and good practice guidance reports.

The IPCC methodologies for estimating and reporting **national** greenhouse gas inventories are based on **sectoral** guidance for reporting of actual emissions and removals of greenhouse gases by gas and **by year**. The *IPCC Guidelines* give the framework for the reporting (sectors, categories and sub-categories), default methodologies and default emission/removal factors (the so called Tier 1 methodologies) for the estimation. Higher tier methodologies are based on more sophisticated methods for estimating emissions/removals and on the use of national or regional parameters that accommodate the specific national circumstances. These methodologies are not always described in detail in the IPCC Guidelines. Use of transparent and well-documented national methodologies consistent with those in the *IPCC Guidelines* is encouraged.

The Good Practice Guidance (GPG) reports facilitate the development of inventories in which the emissions/removals are not over- or under-estimated, so far as can be judged, and in which the uncertainties are reduced as far as practicable. Further aims are to produce transparent, documented, consistent, complete, comparable inventories, which are i) assessed for uncertainties, ii) subject to quality assurance and quality control, and iii) efficient in the use of resources. The GPG reports give guidance on how to choose the appropriate methodologies for specific categories in a country, depending on the importance of the category (key category analysis is used to determine the importance) and on availability of data and resources for the estimation. Decision trees guide the choice of estimation method most suited to the national circumstances. The category-specific guidance linked to the decision trees also provides information on the choice of emission factors and activity data. The GPG reports give guidance on how to meet the requirements of transparency, consistency, completeness, comparability, and accuracy required by the national greenhouse gas inventories.

The **Sectors** covered in the *IPCC Guidelines* are: (i) Energy, (ii) Industrial Processes, (iii) Solvent and Other Product Use, (iv) Agriculture, (v) Land Use Change and Forestry, (vi) Waste and (vii) Other. The use of the seventh sector 'Other' is discouraged: 'Efforts should be made to fit all emission sources/sinks into the six categories described above. If it is impossible to do so, however, this category can be used, accompanied by a detailed explanation of the source/sink activity'' (IPCC 1997).

- Sink enhancement: To evaluate the CCS systems using an analogy with the treatment made to CO_2 removals by sinks in the sector Land Use, Land-Use Change and Forestry. A balance is made of the CO_2 emissions and removals to obtain the net emission or removal. In this option, removals by sinks are related to CO_2 storage.

In both options, estimation methodologies could be developed to cover most of the emissions in the CCS system (see Figure 9.1), and reporting could use the current framework for preparation of national greenhouse gas inventories.

In the first option, reduced emissions could be reported in the category where capture takes place. For instance, capture in power plants could be reported using lower emission factors than for plants without CCS. But this could reduce transparency of reporting and make review of the overall impact on emissions more difficult, especially if the capture process and emissions from transportation and storage are not linked. This would be emphasized where transportation and storage includes captured CO_2 from many sources, or when these take place across national borders. An alternative would be to track CO_2 flows through the entire capture and storage system making transparent how much CO_2 was produced, how much was emitted to the atmosphere at each process stage, and how much CO_2 was transferred to storage. This latter approach, which appears fully transparent and consistent with earlier UNFCCC agreements, is described in this chapter.

The second option is to report the impact of the CCS system as a sink. For instance, reporting of capture in power plants would not alter the emissions from the combustion process but the stored amount of CO_2 would be reported as a removal in the inventory. Application of the second option would require adoption of new definitions not available in the UNFCCC or in the current methodological framework for the preparation of inventories. UNFCCC (1992) defines a sink as 'any process, activity or mechanism which removes a greenhouse gas, an aerosol, or a precursor of a greenhouse gas *from the atmosphere*'. Although 'removal' was not included explicitly in the UNFCCC definitions, it appears associated with the 'sink' concept. CCS[11] systems do not meet the UNFCCC definition for a sink, but given that the definition was agreed without having CCS systems in mind, it is likely that this obstacle could be solved (Torvanger *et al*., 2005).

General issues of relevance to CCS systems include system boundaries (sectoral, spatial and temporal) and these will vary in importance with the specific system and phases of the system. The basic methodological approaches for system components, together with the status of the methods and availability of data for these are discussed below. Mineral carbonation and industrial use of CO_2 are addressed separately.

- Sectoral boundaries: The draft outline for the *2006 IPCC Guidelines* (see Section 9.2.1) states that: 'CO_2 capture activities will be integrated as appropriate into the methods presented for source/sink categories where they may

[11] Few cases are nearer to the 'sink' definition. For example, mineralization can also include fixation from the atmosphere.

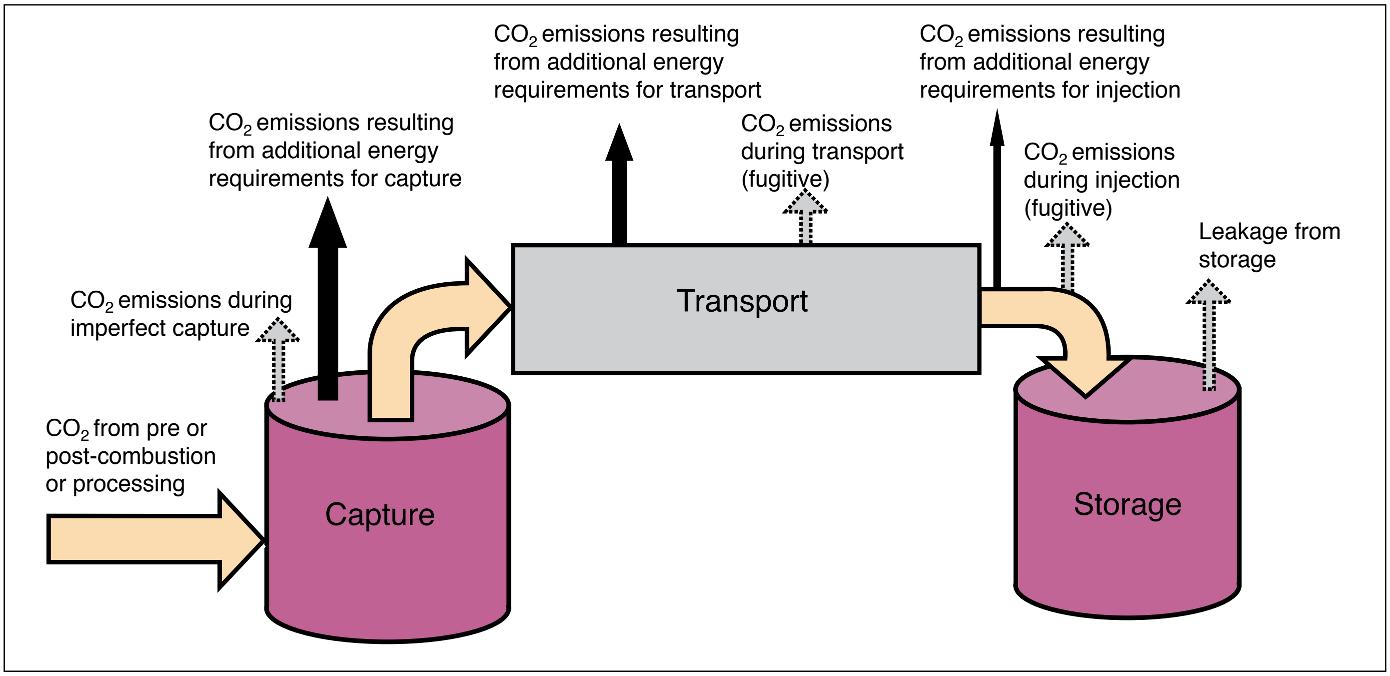

Figure 9.1 Simplified flow diagram of possible CO_2 emission sources during CCS

occur'. This approach is followed here when addressing the sectors under which the specific phases of the CCS systems could be reported. The reporting of emissions/removals associated with CO_2 capture, transportation, injection and storage processes should be described clearly to fulfil the requirement of transparent reporting.

- Spatial boundaries: National inventories include greenhouse gas emissions and removals taking place within national (including administered) territories and offshore areas over which that country has jurisdiction. Some of the emissions and removals of CCS systems could occur outside the areas under the jurisdiction of the reporting country, an aspect that requires additional consideration and is addressed mainly in Section 9.3.
- Temporal boundaries: Inventories are prepared on a calendar year basis. Some aspects of CCS systems (such as the amount of CO_2 captured or fugitive emissions from transportation) could easily be incorporated into an annual reporting system (yearly estimates would be required). However, other emissions (for example, physical leakage of CO_2 from geological storage) can occur over a very long period after the injection has been completed - time frames range from hundreds to even millions of years (see further discussion in Section 9.3).

Table 9.1 lists potential sources and emissions of greenhouse gases in the different phases of a CCS system and their relationship with the framework for the reporting (sectors, categories and sub-categories) of the *IPCC Guidelines*. The relative importance of these potential sources for the national greenhouse inventory can vary from one CCS project to another, depending on factors such as capture technologies and storage site characteristics. Emissions from some of these sources are probably very small, sometimes even insignificant, but to guarantee an appropriate completeness[12] of the national inventory, it is necessary to evaluate their contribution.

Some important considerations relative to the source categories and emissions included in Table 9.1 are the following:

- Capture, transportation and injection of CO_2 into storage requires energy (the additional energy requirements have been addressed in previous chapters). Greenhouse gas emissions from this energy use are covered by the methodologies and reporting framework in the *IPCC Guidelines* and *GPG2000*. Additional methodologies and emission factors can be found in other extensive literature, such as EEA (2001) and US EPA (1995, 2000). Where capture processes take place at the fuel production site, the emissions from the fuel used in the capture process may not be included in the national statistics. Additional methods to cover emissions from this source may be needed. In the current reporting framework, emissions from the additional energy requirements would not be linked to the CCS system.
- Fugitive emissions from CCS systems can occur during capture, compression, liquefaction, transportation and injection of CO_2 to the storage reservoir. A general framework for estimation of fugitive emissions is included in the *IPCC Guidelines* in the Energy sector. The estimation and reporting of fugitive emissions from CCS need further

[12] Completeness means that an inventory covers all sources and sinks, as well as all gases included in the IPCC Guidelines and also other existing relevant source/sink categories specific to individual Parties, and therefore may not be included in the IPCC Guidelines. Completeness also means full geographic coverage of sources and sinks of a Party (FCCC/CP/1999/7).

Table 9.1 Potential sources and emissions of greenhouse gases (GHG) in the general phases of a CCS system.

IPCC guidelines			**Emissions**	**Capture**	**Transportation** [b]	**Injection**	**Storage** [c]
Sector [a]	**Source category** [a]						
1 Energy	GHG emissions from stationary combustion 1A1; 1A2		CO_2, CH_4, N_2O, NO_x, CO, NMVOCs, SO_2	•		•	
1 Energy	GHG emissions from mobile combustion	Water-borne navigation 1A3di [d] 1A3dii [e]	CO_2, CH_4, N_2O, NO_x, CO, NMVOCs, SO_2		•		
		Other transportation (pipeline transportation) 1A3ei	CO_2, CH_4, N_2O, NO_x, CO, NMVOCs, SO_2		•		
1 Energy	Fugitive emissions from fuels 1B	Oil and natural gas 1B2 [f]	CO_2; CH_4; N_2O NMVOCs	•		•	
2 Industrial processes (excluding emissions from fuel combustion)	Mineral products 2A	(e.g., cement)	CO_2, SO_2	•		•	
	Chemical industry 2B	(e.g., ammonia)	CO_2, NMVOCs, CO, SO_2	•		•	
	Metal production 2C	(e.g., iron and steel)	CO_2, NO_x, NMVOCs, CO, SO_2	•		•	
	Other production 2D	(e.g. food and drink)	CO_2, NMVOCs	•		•	
6 Waste	Industrial wastewater handling 6B1		CH_4	•			
	Fugitive CO_2 emissions from capture, transportation and injection processes [g]	Normal operations	CO_2	•	•	•	
		Repair and maintenance	CO_2	•	•	•	
		Systems upsets and accidental discharges	CO_2	•	•	•	

a) IPCC source/sink category numbering (see also IPCC (1997), Vol.1, Common Reporting Framework).

b) Emissions from transportation include both GHG emissions from fossil fuel use and fugitive emissions of CO_2 from pipelines and other equipment/processes. Besides ships and pipelines, limited quantities of CO_2 could be transported by railway or by trucks, source categories identified in the IPCC Guidelines/GPG2000.

c) Long-term physical leakage of stored CO_2 is not covered by the existing framework for reporting of emissions in the *IPCC Guidelines*. Different potential options exist to report these emissions in the inventories (for example, in the relevant sectors/categories producing the emissions, creating a separate and new category for the capture, transportation and/or storage industry). No conclusion can yet be made on the most appropriate reporting option taking into account the different variants adopted by the CCS systems.

d) International Marine (Bunkers). Emissions based on fuel sold to ships engaged in international transport should not be included in national totals but reported separately under Memo Items.

e) National Navigation.

f) Emissions related to the capture (removal) of CO_2 in natural gas processing installations to improve the heating valued of the gas or to meet pipeline specifications.

g) A general framework for estimation of fugitive emissions is included in the *IPCC Guidelines* in the Energy sector. However, estimation and reporting of fugitive emissions from CCS needs further elaboration of the methodologies.

elaboration in methodologies.

- The long-term physical leakage of stored CO_2 (escape of CO_2 from a storage reservoir) is not covered by the existing framework for reporting emissions in the *IPCC Guidelines*. Different options exist to report these emissions in the inventories (for example, in the relevant sectors/categories producing the emissions initially, by creating a separate and new category under fugitive emissions, or by creating a new category for the capture, transportation and/or storage industry).
- Application of CCS to CO_2 emissions from biomass combustion, and to other CO_2 emissions of biological origin (for example, fermentation processes in the production of food and drinks) would require specific treatment in inventories. It is generally assumed that combustion of biomass fuels results in zero net CO_2 emissions if the biomass fuels are produced sustainably. In this case, the CO_2 released by combustion is balanced by CO_2 taken up during photosynthesis. In greenhouse gas inventories, CO_2 emissions from biomass combustion are, therefore, not reported under Energy. Any unsustainable production should be evident in the calculation of CO_2 emissions and removals in Land Use, Land-Use Change and Forestry Sector. Thus, CCS from biomass sources would be reported as negative CO_2 emissions.

9.2.2.1 Capture

The capture processes are well defined in space and time, and their emissions (from additional energy use, fugitives, etc.) could be covered by current national and annual inventory systems. The capture processes would result in reduced emissions from industrial plants, power plants and other sites of fuel combustion. For estimation purposes, the reduced CO_2 emissions could be determined by measuring the amount of CO_2 captured and deducting this from the total amount of CO_2 produced (see Figure 8.2 in Chapter 8).

The total amount of CO_2, including emissions from the additional energy consumption necessary to operate the capture process, could be estimated using the methods and guidance in the *IPCC Guidelines* and *GPG2000*. The capture process could produce emissions of other greenhouse gases, such as CH_4 from treatment of effluents (for example, from amine decomposition). These emissions are not included explicitly in the *IPCC Guidelines* and *GPG2000*. Estimates on the significance of these emissions are not available, but are likely to be small or negligible compared to the amount of captured CO_2.

Although not all possible CCS systems can be considered here, it is clear that some cases would require different approaches. For example, pre-combustion decarbonization in fuel production units presents some important differences compared to the post-combustion methods, and the simple estimation process described above might not be applicable. For example, the capture of CO_2 may take place in a different country than the one in which the decarbonized fuel is used. This would mean that emissions associated with the capture process (possible fugitive CO_2 emissions) would need to be estimated and reported separately to those resulting from the combustion process (see also Section 9.3 on issues relating to accounting and allocation of the emissions and emissions reductions).

9.2.2.2 Transportation

Most research on CCS systems focuses on the capture and storage processes and fugitive emissions from CO_2 transportation are often overlooked (Gale and Davison, 2002). CO_2 transportation in pipelines and ships is discussed in Chapter 4. Limited quantities of CO_2 could also be transported via railway or by trucks (Davison *et al*., 2001). The additional energy required for pipeline transport is mostly covered by compression at the capture site. Additional compression may be required when CO_2 is transported very long distances. The emissions from fossil fuel in transportation by ships, rail or trucks would be covered under the category on mobile combustion and other subcategories in the Energy sector. However, according to the current IPCC guidelines, emissions from fuels sold to any means of international transport should be excluded from the national total emissions and be reported separately as emissions from international bunkers. These emissions are not included in national commitments under the Kyoto Protocol (e.g., IPCC 1997 and 2000, see also Section 9.3).

Any fugitive emissions or accidental releases from transportation modes could be covered in the Energy sector under the category 'Fugitive Emissions'. CO_2 emissions from a pipeline can occur at the intake side during pumping and compression, at the pipeline joints, or at the storage site. Emission rates can differ from surface, underground and sub-sea pipelines. Explicit guidance for CO_2 transportation in pipelines is not given in the current IPCC methodologies, but a methodology for natural gas pipelines is included. A distinction is to be made between leakage during normal operation and CO_2 losses during accidents or other physical disruptions. As described in Chapter 4, statistics on the incident rate in pipelines for natural gas and CO_2 varied from 0.00011 to 0.00032 incidents km^{-1} $year^{-1}$ (Gale and Davison, 2002). However, as an analogy of CO_2 transportation to natural gas transportation, Gielen (2003) reported that natural gas losses during transportation can be substantial.

Total emissions from pipelines could be calculated on the basis of the net difference between the intake and discharge flow rates of the pipelines. Because CO_2 is transported in pipelines as a supercritical or dense phase fluid, the effect of the surrounding temperature on the estimated flow rate would need to be taken into account. Volumetric values would need to be corrected accordingly when CO_2 is transmitted from a cooler climate to a moderate or hot climate, and vice versa. In some cases, fugitive losses could be lower than metering accuracy tolerances. Hence, all metering devices measuring CO_2 export and injection should be to a given standard and with appropriate tolerances applied. But metering uncertainties may prohibit measurement of small quantities of losses during transportation. For transportation by CO_2 pipeline across the borders of several countries, emissions would need to be allocated to the countries where they occur.

No methodologies for estimation of fugitive emission from ship, rail or road transportation are included in the IPCC Guidelines.

9.2.2.3 Storage

Some estimates of CO_2 emissions (physical leakage rates) from geological and ocean storage are given in Chapters 5 and 6. Physical leakage rates are estimated to be very small for geological formations chosen with care. In oil reservoirs and coal seams, storage times could be significantly altered if exploitation or mining activities in these fields are undertaken after CO_2 storage. Some of the CO_2 injected into oceans would be released to the atmosphere over a period of hundreds to thousands of years, depending on the depth and location of injection.

The amount of CO_2 injected or stored could be easily measured in many CCS systems. Estimation of physical leakage rates would require the development of new methodologies. Very limited data are available in relation to the physical leakage of CO_2.

Despite the essential differences in the nature of the physical processes of CO_2 retention in oceans, geological formations, saline aquifers and mineralized solids, the mass of CO_2 stored over a given time interval can be defined by the Equation 1.

$$CO_2\ stored = \int_O^T (CO_2\ injected(t) - CO_2\ emitted(t)dt \qquad (1)$$

where t is time and T is the length of the assessment time period.

Use of this simple equation requires estimates or measurements of the injected CO_2 mass and either default values of the amount of CO_2 emitted from the different storage types, or rigorous source-specific evaluation of mass escaped CO_2. This approach would be possible when accurate measurements of mass of injected and escaped CO_2 are applied on site. Thus, for monitoring possible physical leakage of CO_2 from geological formations, direct measurement methods for CO_2 detection, geochemical methods and tracers, or indirect measurement methods for CO_2 plume detection could be applied (see Section 5.6, Monitoring and verification technology).

Physical leakage of CO_2 from storage could be defined as follows (Equation 2):

$$Emissions\ of\ CO_2\ from\ storage = \int_O^T m(t)dt \qquad (2)$$

where m(t) is the mass of CO_2 emitted to the atmosphere per unit of time and T is the assessment time period.

This addresses physical leakage that might occur in a specific timeframe after the injection, perhaps far into the future. The issue is discussed further in Section 9.3.

9.2.2.4 Mineral carbonation

Mineral carbonation of CO_2 captured from power plants and industrial processes is discussed in Chapter 7. These processes are still under development and aim at permanent fixation of the CO_2 in a solid mineral phase. There is no discussion in the literature about possible modes and rates of physical leakage of CO_2 from mineral carbonation, probably because investigations in this field have been largely theoretical character (for example, Goldberg *et al*., 2000). However, the carbonate produced would be unlikely to release CO_2. Before and during the carbonation process, some amount of gas could escape into the atmosphere.

The net benefits of mineral carbonation processes would depend on the total energy use in the chain from capture to storage. The general framework discussed above for CCS systems can also be applied in preparing inventories of emissions from these processes. The emissions from the additional energy requirements would be seen in the energy sector under the current reporting framework. The amount of CO_2 captured and mineralized could be reported in the category where the capture takes place, or as a specific category addressing mineral carbonation, or in the sector 'Other'.

9.2.2.5 Industrial uses

Most industrial uses of CO_2 result in release of the gas to the atmosphere, often after a very short time period. Because of the short 'storage times', no change may be required in the inventory systems provided they are robust enough to avoid possible double counting or omission of emissions. The benefits of these systems are related to the systems they substitute for, and the relative net efficiencies of the alternate systems. Comparison of the systems would need to take into account the whole cycle from capture to use of CO_2. As an example, methanol production by CO_2 hydrogenation could be a substitute for methanol production from fossil fuels, mainly natural gas. The impacts of the systems are in general covered by current inventory systems, although they are not addressed explicitly, because the emissions and emission reductions are related to relative energy use (reduction or increase depending on the process alternatives).

In cases where industrial use of CO_2 would lead to more long-term carbon storage in products, inventory methodologies would need to be tailored case by case.

9.2.3 Monitoring, verification and uncertainties

The IPCC Guidelines and good practice reports give guidance on monitoring, verification and estimation of uncertainties, as well as on quality assurance and quality control measures. General guidance is given on how to plan monitoring, what to monitor and how to report on results. The purpose of verifying national inventories is to establish their reliability and to check the accuracy of the reported numbers by independent means.

Section 5.6, on monitoring and verification technology, assesses the current status of monitoring and verification techniques for CCS systems. The applicability of monitoring techniques as well as associated detection limits and uncertainties vary greatly depending on the type and specific characteristics of the CCS projects. There is insufficient experience in monitoring CCS projects to allow conclusions to be drawn on physical leakage rates.

Reporting of uncertainties in emission and removal estimates, and how they have been derived, is an essential part of national greenhouse gas inventories. Uncertainty estimates can be based on statistical methods where measured data are available, or on expert judgement. No information on uncertainties related to emissions from different phases of CCS systems was available. In Section 5.7.3, the probability of release from geological storage is assessed based on data from analogous natural or engineered systems, fundamental physical and chemical processes, as well as from experience with current geological storage projects. The probabilities of physical leakage are estimated to be small and the risks are mainly associated with leakage from well casings of abandoned wells.

9.3 Accounting issues

One of the goals of an accounting system is to ensure that CCS projects produce real and quantifiable environmental benefits. One ton of CO_2 permanently stored has the same benefit in terms of atmospheric CO_2 concentrations as one ton of CO_2 emissions avoided. But one ton of CO_2 temporarily stored has less value than one ton of CO_2 emissions avoided. This difference can be reflected in the accounting system. Accounting for CCS may have to go beyond measuring the amount of CO_2 stored in order to ensure the credibility of storage credits and that credits claimed are commensurate with benefits gained. CO_2 storage should not avoid properly accounting for emissions that have been moved to other times, other places, or other sectors. Yet, Kennett (2003) notes that if there is benefit to potentially permanent or even to known temporary storage, accounting systems should contribute to their credibility and transparency while minimizing transaction costs.

In a political environment where only some parties have commitments to limit greenhouse gas emissions and where emissions from all sources are not treated the same, the amount by which emissions are reduced may not be equal to the amount of CO_2 stored. Differences can occur because CO_2 can be captured in one country but released in another country or at a later time. Also, CCs requires energy and likely additional emissions of CO_2 to produce this additional energy. Yoshigahara *et al*. (2004) note that emission reduction through CCS technology differs from many other modes of emission reduction. Although the former avoids CO_2 release to the atmosphere, it creates the long-term possibility that stored CO_2 could eventually flow to the atmosphere through physical leakage.

In this Chapter, the general term 'leakage' is used in the economist's sense, to describe displacement of greenhouse gas emissions beyond the boundaries of the system under discussion. The term 'physical leakage' refers to escape of CO_2 from a storage reservoir. As discussed above, some physical leakage effects and the additional energy requirements will be reported within standard, national reporting procedures for greenhouse gas emissions. Additional complexities arise when new or unexpected sources of emissions occur, for example, if CO_2 injected into an uneconomic coal seam forces the release of methane from that seam. Complexities also arise when new or unexpected sources of emissions occur in different countries, for example, if CO_2 is captured in one country but released in another, or at later times, for example, if CO_2 is captured during one time period and physically leaked to the atmosphere at a later time.

The problems of economic leakage are not unique to CCS systems, but the problems of physical leakage are unique to CCS. In particular, when emission inventories are done by country and year they may fail to report emissions that are delayed in time, displaced to other countries or to international waters, or that stimulate emissions of other greenhouse gases not identified as sources or for which methodologies have not been developed.

In this section, ideas on the issues involved in accounting are summarized for the stored CO_2 of CCS systems. The consequences for mitigating greenhouse gas emissions are discussed, and ideas on alternative accounting strategies to address them are presented. Figure 9.2 provides a simple flow diagram of how CCS emissions can create flows of greenhouse gases that transcend traditional accounting boundaries. The diagram also shows how emissions might escape reporting because they occur outside normal system boundaries (sectoral, national, or temporal) of reporting entities.

Concern about displacement of emissions across national boundaries is a consequence of the political and economic constructs being developed to limit greenhouse gas emissions. Most notably, the Kyoto Protocol imposes limits on greenhouse gas emissions from developed countries and from countries with economies in transition, but no such limits on emissions from developing countries or international transport.

Concern about displacement of emissions across temporal boundaries is essentially the widely posed question: 'if we store carbon away from the atmosphere, how long must it be stored?' The same question is phrased by Herzog *et al*. (2003) as 'What is the value of temporary storage?'

Concern about leakage among countries, sectors, or gases; or physical leakage from reservoirs is largely about the completeness and accuracy of emissions accounting. Kennett (2003), for example, emphasizes the importance of 'establishing general rules and procedures to simplify transactions, and increasing certainty by defining legal rights and by providing dispute resolution and enforcement procedures' and of ensuring the credibility of sinks-based emissions offsets or storage-based emissions reductions. The operation of a market requires clearly defined rights (i.e. who has the rights to the carbon stored), what those rights entail, how those rights can be transferred, and liability and remedies in the event of unanticipated release (Kennett, 2003). The core of establishing rights, liabilities, and markets will be the accounting and certification systems. Yet, a well-designed accounting system should not lead to transaction costs that unnecessarily discourage meritorious activities.

9.3.1 Uncertainty, non-permanence and discounting methodology

9.3.1.1 Dealing with the impermanence of carbon dioxide storage

CO_2 storage is not necessarily permanent. Physical leakage from storage reservoirs is possible via (1) gradual and long-term release or (2) sudden release of CO_2 caused by disruption of the reservoir. There is very little literature on accounting for the potential impermanence of CCS. There are, however, a significant number of publications on accounting for the impermanence of CO_2 sequestration in the terrestrial biosphere. Although sequestration in the terrestrial biosphere is notably different from CO_2 storage in the ocean or in geological reservoirs, there are also similarities. [13]CO_2 stored in the terrestrial biosphere is subject to potential future release if, for example, there is a wildfire, change in land management practices, or climate change renders the vegetative cover unsustainable. Although the risks of CO_2 loss from well-chosen geological reservoirs are very different, such risks do exist. The literature suggests various accounting strategies so that sequestration in the biosphere could be treated as the negative equivalent of emissions. Sequestration could be shown in national emission accounts and trading of emissions credits, and debits between parties could occur for sequestration activities in the terrestrial biosphere. Whether CCS is treated as a CO_2 sink or as a reduction in emissions, the issues of accounting for physical leakage from storage are similar.

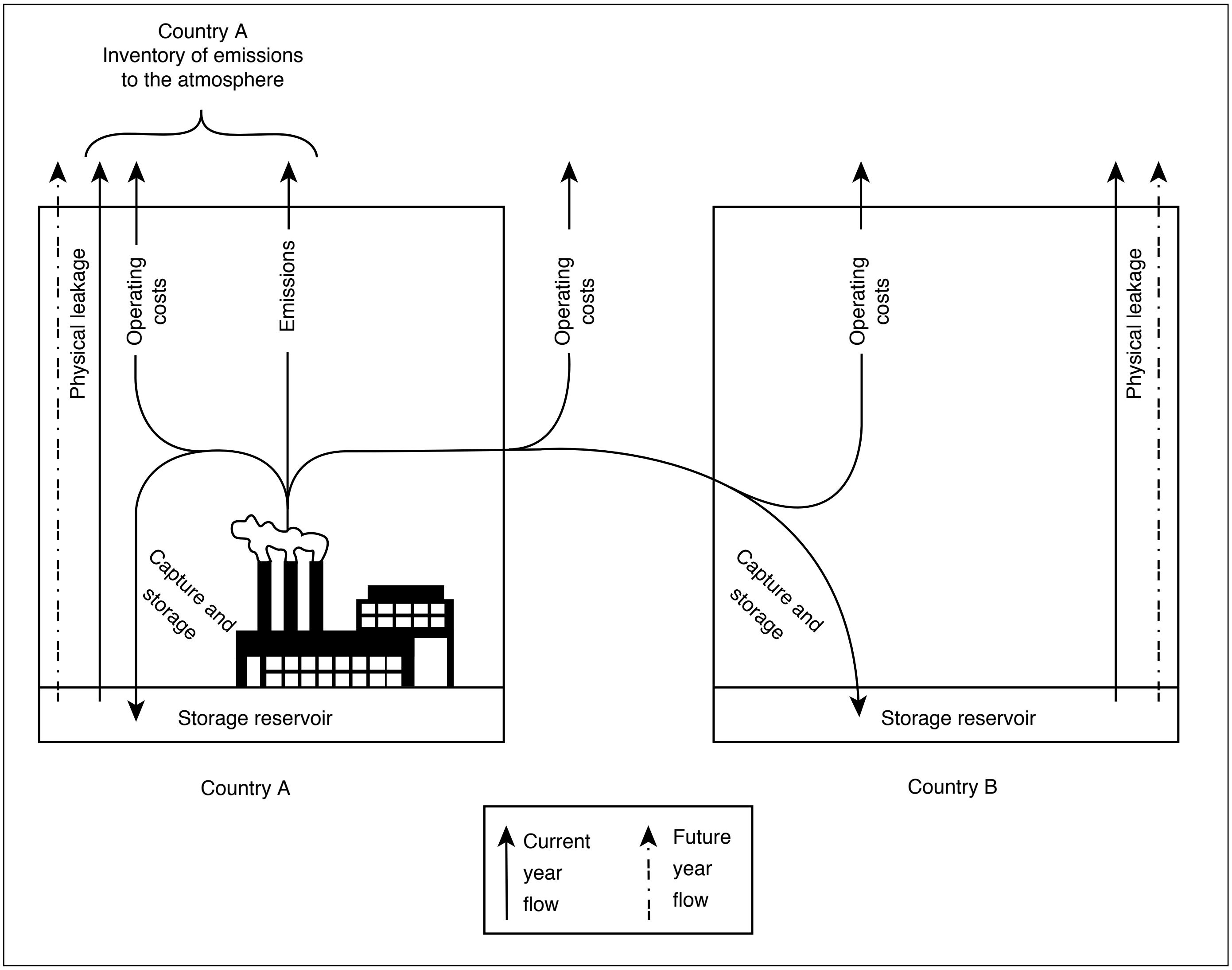

Figure 9.2 Simplified flow diagram showing how CCS could transcend traditional accounting boundaries[13]

[13] The operating cost shown are the CO_2 emitted as a result of the additional energy required to operate the system, plus fugitive emissions from separation, transport and injection.

Chomitz (2000) suggests two primary approaches to accounting for stored CO_2: (1) acknowledge that CO_2 storage is likely not permanent, assess the environmental and economic benefits of limited-term storage, and allot credits in proportion to the time period over which CO_2 is stored, and (2) provide reasonable assurance of indefinite storage. Examples discussed for sequestration in the terrestrial biosphere include (under the first approach) ton-year accounting (described below); and (under the second approach) various combinations of reserve credits and insurance replacing lost CO_2 by sequestration reserves or other permanent emissions reductions. For further discussion on these issues, see Watson *et al*., 2000; Marland *et al*., 2001; Subak, 2003; Aukland *et al*., 2003; Wong and Dutschke, 2003; and Herzog *et al*., 2003. There are also proposals to discount credits so that there is a margin of conservativeness in the number of credits acknowledged. With this kind of discussion and uncertainty, negotiations toward the Kyoto Protocol have chosen to place limits on the number of credits that can be claimed for some categories of terrestrial CO_2 sequestration during the Protocol's first commitment period (UNFCCC, 2002).

To illustrate the concept of allotting credits in proportion to storage time, one alternative, the ton-year approach is described. The ton-year alternative for accounting defines an artificial equivalence so that capture and storage for a given time interval (for example, t years) are equated with permanent storage. Availability of credits can be defined in different ways but typically capture and storage for one year would result in a number of credits equal to 1/t, and thus storage for t years would result in one full credit (Watson *et al*., 2000). A variety of constructs have been proposed for defining the number of storage years that would be equated with permanent storage (see, for example, Marland *et al*., 2001). But as Chomitz (2000) points out, despite being based on scientific and technical considerations, this equivalence is basically a political decision. Although ton-year accounting typifies the first approach, it has been subject to considerable discussion. Another derivative of Chomitz's first approach that has been further developed within negotiations on the Kyoto Protocol (Columbia, 2000; UNFCCC, 2002; UNFCCC, 2004) is the idea of expiring credits or rented temporary credits (Marland et el., 2001; Subak, 2003). Temporary or rented credits would have full value over a time period defined by rule or by contract, but would result in debits or have to be replaced by permanent credits at expiration. In essence, credit for stored CO_2 would create liability for the possible subsequent CO_2 release or commitment to storage was ended.

UNFCCC (2002), Marland et al. (2001), Herzog et al. (2003), and others agree that the primary issue for stored CO_2 is liability. They argue that if credit is given for CO_2 stored, there should be debits if the CO_2 is subsequently released. Physical leakage from storage and current emissions produce the same result for the atmosphere. Accounting problems arise if ownership is transferred or stored CO_2 is transferred to a place or party that does not accept liability (for example, if CO_2 is stored in a developing country without commitments under the Kyoto protocol). Accounting problems also arise if potential debits are transferred sufficiently far into the future with little assurance that the systems and institutions of liability will still be in place if and when CO_2 is released. The system of expiring credits in the Marrakech Accords for sequestration in the terrestrial biosphere fulfils the requirement of continuing liability. Limiting these credits to five years provides reasonable assurance that the liable institutions will still be responsible. This arrangement also addresses an important concern of those who might host CO_2 storage projects, that they might be liable in perpetuity for stored CO_2. Under most proposals, the hosts for CO_2 storage would be liable for losses until credits expire and then liability would return to the purchaser/renter of the expiring credits. Kennett (2003) suggests that long-term responsibility for regulating, monitoring, certifying, and supporting credits will ultimately fall to governments (see also section 5.8.4). With this kind of ultimate responsibility, governments may wish to establish minimum requirements for CCS reservoirs and projects (see Torvanger *et al*., 2005).

The published discussions on 'permanence' have largely been in the context of sequestration in the terrestrial biosphere. It is not clear whether the evolving conclusions are equally appropriate for CCS in the ocean or in geological reservoirs. Important differences between modes of CCS may influence the accounting scheme chosen (see Table 9.2). An apparent distinction is that sequestration in the terrestrial biosphere involves initial release of CO_2 to the atmosphere and subsequent removal by growing plants. But as storage in geological reservoirs does not generally involve release to the atmosphere, it might be envisioned as a decrease in emissions rather than as balancing source with sink. In either case, a mass of CO_2 must be managed and isolated from the atmosphere. Storage in the terrestrial biosphere leaves open the possibility that sequestration will be reversed because of decisions on maintenance or priorities for resource management. Ocean and geological storage have very different implications for the time scale of commitments and for the role of physical processes versus decisions in potential physical releases.

An important question for crediting CCS is whether future emissions have the same value as current emissions. Herzog *et al*. (2003) define 'sequestration effectiveness' as the net benefit from temporary storage compared to the net benefit of permanent storage, but this value cannot be known in advance. They go one step further and argue that while CO_2 storage is not permanent, reducing emissions may not be permanent either, unless some backstop energy technology assures all fossil fuel resources are not eventually consumed. According to Herzog *et al*. (2003), stored CO_2 emissions are little different, to fossil fuel resources left in the ground. Most analysts, however, assume that all fossil fuels will never be consumed so that refraining from emitting fossil-fuel CO_2 does not, like CO_2 storage, give rise directly to a risk of future emissions. Wigley *et al*. (1996) and Marland *et al*. (2001) argue that there is value in delaying emissions. If storage for 100 years were to be defined as permanent, then virtually all carbon injected below 1500 m in the oceans would be considered to be permanent storage (Herzog *et al*., 2003).

Table 9.2 Differences between forms of carbon storage with potential to influence accounting method.

Property	Terrestrial biosphere	Deep ocean	Geological reservoirs
CO_2 sequestered or stored	Stock changes can be monitored over time.	Injected carbon can be measured	Injected carbon can be measured
Ownership	Stocks will have a discrete location and can be associated with an identifiable owner.	Stocks will be mobile and may reside in international waters.	Stocks may reside in reservoirs that cross national or property boundaries and differ from surface boundaries.
Management decisions	Storage will be subject to continuing decisions about land-use priorities.	Once injected, no further human decisions on maintenance.	Once injected, human decisions to influence continued storage involve monitoring and perhaps maintenance, unless storage interferes with resource recovery.
Monitoring	Changes in stocks can be monitored.	Changes in stocks will be modelled.	Release of CO_2 might be detected by physical monitoring but because of difficulty in monitoring large areas may also require modelling.
Time scale with expected high values for fraction CO_2 retained	Decades, depending on management decisions.	Centuries, depending on depth and location of injection.	Very small physical leakage from well-designed systems expected, barring physical disruption of the reservoir.
Physical leakage	Losses might occur due to disturbance, climate change, or land-use decisions.	Losses will assuredly occur as an eventual consequence of marine circulation and equilibration with the atmosphere.	Losses are likely to be small for well-designed systems except where reservoir is physically disrupted.
Liability	A discrete land-owner can be identified with the stock of sequestered carbon.	Multiple parties may contribute to the same stock of stored carbon and the carbon may reside in international waters.	Multiple parties may contribute to the same stock of stored carbon lying under several countries.

At the other temporal extreme, Kheshgi *et al*. (1994) point out that over the very long term of equilibration between the ocean and atmosphere (over 1000 years), capture and storage in the ocean will lead to higher CO_2 levels in the atmosphere than without emissions controls, because of the additional energy requirements for operating the system. It is also true that chronic physical leakage over long time periods could increase the difficulty of meeting targets for net emissions at some time in the future (see Hawkins, 2003; Hepple and Benson, 2003; and Pacala, 2003).

The fundamental question is then, how to deal with impermanent storage of CO_2. Although Findsen *et al*. (2003) detail many circumstances where accounting for CCS is beginning or underway, and although the rates of physical leakage for well-designed systems may sometimes be in the range of the uncertainty of other components of emissions, the risks of physical leakage need to be acknowledged. A number of questions remains to be answered: how to deal with liability and continuity of institutions in perpetuity, how to quantify the benefits of temporary storage; the needs in terms of monitoring and verification, whether or not there is a need for a reserve of credits or other ways to assure that losses will be replaced, whether or not there is need for a system of discounting to consider expected or modelled duration of storage, the utility of expiring, temporary, or rented credits over very long time periods, whether there is a need to consider different accounting practices as a function of expected duration of storage or mode of storage. The implications if storage in the terrestrial biosphere and in geological formations are sufficiently different that the former might be considered carbon management and the latter CO_2 waste disposal.

Ultimately, the political process will decide the value of temporary storage and the allocation of responsibility for stored CO_2. Some guidance is provided by precedents set by international agreements on sequestration in the terrestrial biosphere. But there are important differences to be considered. The reason for rules and policies is presumably to influence behaviour. Accounting rules for CO_2 storage can best influence permanence if they are aimed accordingly: at liability for CO_2 stored in the terrestrial biosphere but at the initial design and implementation requirements for CCS in the oceans or geological reservoirs.

9.3.1.2 Attribution of physical leakage from storage in international/regional territories or shared facilities and the use of engineering standards to limit physical leakage

The previous section deals largely with the possibility that CO_2 emissions stored now will be released at a later time. It also introduces the possibility that emissions stored now will result in additional, current emissions in different countries or in different sectors. CO_2 injected into the ocean could leak physically from international waters. Accounting for stored CO_2 raises questions such as responsibility for the emissions from energy used in CO_2 transport and injection, especially if transport and/or storage is in a developing country or in international waters. Similarly, questions about physical leakage of stored CO_2 will need to address liability for current year physical leakage that occurs in developing countries or from international waters. These questions may be especially complex when multiple countries have injected CO_2 into a common reservoir such as the deep Atlantic Ocean, or into a deep aquifer under multiple countries, or if multiple countries share a common pipeline for CO_2 transport.

There may also be a need for international agreement on certification of CCS credits or performance standards for CCS projects. Standards would minimize the risk of leakage and maximize the time for CO_2 storage. Performance standards could minimize the possibility of parties looking for the least cost, lowest quality storage opportunities - opportunities most susceptible to physical leakage - when liability for spatial or temporal leakage is not clear. Performance standards could be used to limit the choice of technologies, quality of operations, or levels of measurement and monitoring.

9.3.2 Accounting issues related to Kyoto mechanisms (JI[14] , CDM[15], and ET[16])

CCS is not currently addressed in the decisions of the COP to the UNFCCC in relation to the Kyoto mechanisms. Little guidance has been provided so far by international negotiations regarding the methodologies to calculate and account for project-related CO_2 reductions from CCS systems under the various project-based schemes in place or in development. The only explicit reference to CCS in the Kyoto Protocol states that Annex I countries need to "research, promote, develop and increasingly use CO_2 sequestration technologies"[17]. The Marrakech Accords further clarify the Protocol regarding technology cooperation, stating that Annex I countries should indicate how they give priority to cooperation in the development and transfer of technologies relating to fossil fuel that capture and store greenhouse gases (Paragraph 26, Decision 5/CP.7). No text referring explicitly to CCS project-based activities can be found in the CDM and JI-related decisions (Haefeli *et al*., 2004).

Further, Haefeli *et al*. (2004) note that CCS is not explicitly addressed in any form in CO_2 reporting schemes that include projects (i.e., the Chicago Climate Exchange and the EU Directive for Establishing a Greenhouse Gas Emissions Trading Scheme (implemented in 2005) along with the EU Linking Directive (linking the EU Emissions Trading Scheme with JI and the CDM). At present, it is unclear how CCS will be dealt with in practice. According to Haines *et al*. (2004), the eligibility of CCS under CDM could be resolved in a specific agreement similar to that for land use, land-use change and forestry (LULUCF) activities. As with biological sinks, there will be legal issues as well as concerns about permanence and economic leakage, or emissions outside a system boundary. At the same time, CCS could involve a rather less complex debate because of the geological time scales involved. Moreover, Haefeli *et al*. (2004) noted that guidelines on how to account for CO_2 transfers between countries would need to be agreed either under the UNFCCC or the Kyoto Protocol. Special attention would need to be given to CO_2 exchange between an Annex I country and a non-Annex I country, and between an Annex I country party to the Kyoto Protocol and an Annex I country that has not ratified the Kyoto Protocol.

9.3.2.1 Emission baselines

The term 'baseline', used mostly in the context of project-based accounting, is a hypothetical scenario for greenhouse gas emissions in the absence of a greenhouse gas reduction project or activity (WRI, 2004). Emission baselines are the basis for calculation of net reductions (for example, storage) of emissions from any project-based activity. Baselines need to be established to show the net benefits of emissions reductions. The important issue is to determine which factors need to be taken into account when developing an emissions baseline. At present, there is little guidance on how to calculate net reductions in CO_2 emissions through CCS project-based activities. An appropriate baseline scenario could minimize the risk that a project receives credits for avoiding emissions that would have been avoided in the absence of the project (Haefeli *et al*., 2004).

9.3.2.2 Leakage in the context of the Kyoto mechanisms

The term 'Leakage' is defined according to Marrakech Accords as 'the net change of anthropogenic emissions by sources and/or removals by sinks of greenhouse gases which occurs outside

[14] Kyoto Protocol Article 6.1 'For the purpose of meeting its commitments under Article 3, any Party included in Annex I may transfer to, or acquire from, any other such Party emission reduction units resulting from projects aimed at reducing anthropogenic emissions by sources or enhancing anthropogenic removals by sinks of greenhouse gases in any sector of the economy…'

[15] Kyoto Protocol Article 12.2 'The purpose of the clean development mechanism shall be to assist Parties not included in Annex I in achieving sustainable development and in contributing to the ultimate objective of the Convention, and to assist Parties included in Annex I in achieving compliance with their quantified emission limitation and reduction commitments under Article 3.'

[16] Kyoto Protocol Article 17 'The Conference of the Parties shall define the relevant principles, modalities, rules and guidelines, in particular for verification, reporting and accountability for emissions trading. The Parties included in Annex B may participate in emissions trading for the purpose of fulfilling their commitments under Article 3. Any such trading shall be supplemental to domestic actions for the purpose of meeting quantified emission limitation and reduction commitments under that Article.'

[17] Article 2, 1(a) (iv) of the Kyoto Protocol.

Table 9.3 Accounting issues related to Kyoto Mechanisms.

Mechanism	Article in the Kyoto Protocol	Principle	Requirements in relation to CCS	Basic considerations
Joint Implementation (JI)	Article 6.1	As a general principle, any Annex I party may transfer to or obtain from another Annex I party Emission Reduction Units (ERUs) that shall result from projects that seek to reduce GHG emissions by sources and/or enhance removals by sinks.	• Set modalities and procedures to set the project in a transparent manner • Procedures for verification and certification of ERU.	Important to ensure that credits received from projects in Annex I countries result from emission reductions that are real and additional to what would have happened in the absence of the project i.e. are measured against baselines.
Clean Development Mechanism (CDM)	Article 12.2	• Intended to promote sustainable develop-ment in developing countries through the allowance of trade between developed and developing countries. • Refers to the establishment of a CDM with the objective of assisting Annex I parties to achieve part of their Article 3 KP emission reduction commitments through the implementation of project-based activities generating emission cut/backs and/or enhanced sink removals.	Highly detailed set of modalities and procedures regarding issues such as: • project level versus national level obligations • modelled versus actual amounts of credits • timing of storage and liabilities in the long term.	• Overall baseline methodology • Annex I parties shall be able to acquire Certified Emission Reductions (CERs) from projects implemented in non Annex I countries. • Should provide real, measurable and long-term benefits related to the mitigation of climate change, i.e. will be measured against baselines.
Emission Trading (ET)	Article 17	Allows for trading between developed countries that have targets and assigned amount units (AAUs) allocated to them through the KP, it endorses the basic principle of the use of ET as a mean available to Annex I parties to achieve their emission commitment.	• Cap (emission trading) i.e. the maximum amount of allowable emission offsets between Annex I countries; • Net versus gross accounting (measures in non-Annex I).	• Trade is based on national Assigned Amounts (AAUs) to individual countries. • The proposed guidelines for ET contain provisions on the amount of AAUs that may be traded between Annex I parties so as to avoid overselling of quotas. It also contains several options that would impose a quantified upper limit on the amount of AAUs that a transferring party could trade. • A successful carbon trading system must accurately measure the offsets and credits to assure companies that they will receive the reductions.

the project boundary, and that is measurable and attributable to the Article 6 project'. The term has been proposed for leakage of emissions resulting from capture, transport and injection, which should not be confused with releases of CO_2 from a geological reservoir (escaped CO_2). According to Haefeli *et al*. (2004), current legislation does not deal with cross-border CCS projects and would need further clarification. Guidance would be especially needed to deal with cross-border projects involving CO_2 capture in an Annex I country that is party to the Kyoto Protocol and storage in a country not party to the Kyoto Protocol or in an Annex I country not bound by the Kyoto Protocol.

Table 9.3 provides an overview of the Kyoto mechanisms and the general principles and requirements of each (practical indices and specific accounting rules and procedures) for developing CCS accounting systems that can be employed for emissions control and reduction within these mechanisms. Although the political process has not yet decided how CCS systems will be accepted under the Kyoto mechanisms, these general procedures could be applicable to them as well as to other similar schemes on emission trading and projects.

9.4 Gaps in knowledge

Methodologies for incorporating CCS into national inventories and accounting schemes are under development. CCS (see Sections 9.2 and 9.3) can be incorporated in different ways and data requirements may differ depending on the choices made. The following gaps in knowledge and need for decisions by the political process have been identified:

- Methodologies to estimate physical leakage from storage, and emission factors (fugitive emissions) for estimating emissions from capture systems and from transportation and injection processes are not available.
- Geological and ocean storage open new challenges regarding a) uncertainty on the permanence of the stored emissions, b) the need for protocols on transboundary transport and storage, c) accounting rules for CCS and, d) insight on issues such as emission measurement, long term monitoring, timely detection and liability/responsibility.
- Methodologies for reporting and verification of reduced emission under the Kyoto Mechanisms have not been agreed upon.
- Methodologies for estimating and dealing with potential emissions resulting from system failures, such as sudden geological faults and seismic activities or pipeline disruptions have not been developed.

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