BELLONA

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UNFCCC Secretariat
UNFCCC Cooperative Mechanisms Programme
Martin-Luther-King-Strasse 8
PO Box 260124
D-53153 Bonn Germany

# Bellona's comments on Carbon dioxide Capture and Storage under the Clean Development Mechanism

## 1. Introduction

Climate change caused by the increased atmospheric concentration of greenhouse gases (GHGs) is one of the biggest challenges our planet faces today. To reduce the global increase in temperature to a maximum of 2°C, it is internationally agreed, and also recommended in the recent IPCC reports, that the global emission levels of GHGs should be reduced by 50-80% before 2050. In order to ensure such a significant amount of emission reductions of GHG gases, a major change throughout the global energy supply chain must take place. This includes enhanced energy efficiency, replacing fossil fuel sources with renewable ones, and replacing polluting energy carriers with electricity and hydrogen.

There is considerable agreement among experts that Carbon dioxide Capture and Storage (CCS) is a vital mitigation alternative for the coming decades. The potential of such technologies to reduce $CO_2$ emissions from fossil fuel power generation is substantial. In addition, a transfer of CCS technologies from industrialised to developing countries can help ensure a more sustainable economic development.

There is an ongoing process concerning the inclusion of Carbon Capture and Storage activities under the Kyoto's flexible market mechanism for developing countries; the Clean Development Mechanism (CDM). The CDM is a significant financial incentive for emission reduction projects in developing countries; consequently the inclusion of CCS under the CDM can contribute to the implementation of CCS in countries where $CO_2$ emissions from fossil fuelled power stations are rapidly increasing.

This paper is submitted by Bellona as an input to specific CCS issues as requested by the COP/MOP2, in addition, CCS and why CCS should be included under the CDM is briefly discussed.

## 2. The Bellona Foundation

The Bellona Foundation is a multi-disciplinary international environmental NGO based in Oslo, Norway with offices in Russia, Washington and Brussels. Founded in 1986 as a direct action protest group, it has since evolved into a highly renowned technology and solution oriented environmental NGO.

Bellona is deeply committed in the fight against global climate change and has produced reports for the public, other NGOs and world leaders offering alternatives to current energy and transportation structures that produce fewer greenhouse gasses in a safe and profitable way. We advocate carbon dioxide emission-free gas production, carbon dioxide capture and sequestration, solar and wind energy to replace old fossil fuel plants. We have taken on the challenge of educating industry and policy makers about the advantages of carbon dioxide sequestration and have produced reports on global CCS potential, on CCS Framework, CCS storage and security as well as a major report on the chain value of $CO_2$ for Enhanced Oil Recovery.

Bellona is also involved in The European Technology Platform for Zero Emission Fossil Fuel Power Plants (ZEP), where we are co-heading the Advisory Council, as well as one of the task forces. ZEP is working to identify and remove barriers to creating zero emission power plants, thus reduce environmental impacts of fossil fuel usage.

Bellona considers Carbon Capture and Storage activities as a vital part of the portfolio of greenhouse gas mitigation initiatives towards stabilising the atmospheric levels of GHG. Bellona also strongly supports strengthening the international efforts to promote technological innovation and transfer, through the Kyoto Protocol or other international endeavours. We believe The Clean Development Mechanism of the Kyoto Protocol (CDM) is an important instrument to foster the introduction of CCS technologies into developing countries; it is therefore a priority for us to contribute to the inclusion of CCS under the CDM.

# 3. Carbon dioxide Capture and Storage (CCS) Background

In order to stabilise the atmospheric concentration of $CO_2$, removing large amounts of $CO_2$ before it is released into the atmosphere through carbon capture and storage (CCS) is an essential tool, as global commercialisation and implementation of renewable energy sources has proven technologically difficult and slow moving. There is a gap between renewable energy production and energy demand, which for the several decades will be filled by fossil fuels. CCS allows the continued use of fossil fuels, while the negative environmental impact is minimised. It is however very important that CCS is supplementary to the continued effort of increasing use of renewable energy as well as energy efficiency measures.

$CO_2$ can be captured from large point sources such as power plants, petrochemical plants, cement, steel and aluminium production, and by storing it safely, primarily in underground deposits, billions of tonnes of emissions can be avoided, thus reducing global warming. The $CO_2$ can be stored in e.g. geological underground formations, at depths of 800-1000 meters or more, at well characterized sites. Storage sites can be deep saline aquifers, depleted oil and gas fields or coal beds.

If biomass, which is $CO_2$ neutral, is used for power and heat production, there will not be any increase the atmospheric $CO_2$ concentration and by combining energy production from biomass with carbon capture and storage (CCS) it is, in fact, possible to obtain a net reduction of $CO_2$ from the atmosphere.

CCS projects are large in nature and also long term, requiring high upfront investments and a long term operation perspective, something that has caused difficulties for the large scale initiation of such projects. However, the two main obstacles to the immediate deployment of CCS are the risk (and cost) aspects; as well as an insufficiently defined regulatory framework for $CO_2$ storage. In the $CO_2$ project value chain, the capturing process amounts to a large part of the investment costs. At the same time, this equipment has the greatest potential to technologically improve and greatly reduce the total project costs. However, considering costs of CCS; the cost of not reducing/avoiding emissions must also be considered; as climate change will have significant detrimental economic consequences, especially in developing countries.

When laying out the regulatory frameworks for CCS operations, particularly the site selection, the scale of operation and the risks associated with performance predictions and potential seepage, as well as liability need to be considered. Regulations that take into account the technical barriers and issues are needed that specifically address the site selection, classification of carbon dioxide ($CO_2$), access and property rights, intellectual property rights (IPR), monitoring and verification requirements, safety assessment and liability. In addition, the definition of $CO_2$ (industrial or waste product) and the process by which it is stored is crucial for determining the type and jurisdiction of the regulations covering CCS activities; this distinction is important as industrial projects typically are subject to less stringent environmental regulations than waste disposal projects [2]. The impact of impurities in a CCS stream must be considered through all stages of a CCS process because their presence affects the engineering processes of capture, transport and injection, as well as the trapping mechanisms and capacity for $CO_2$ storage in geological media [1]. How $CO_2$ is classified also determines its legality and treatment under international treaties and national laws and regulations e.g. the London Convention [3].

With a rapid growth in the number and scope of CCS projects worldwide the lack of a clear, defined legal and regulatory framework in which to operate is of great concern, especially from a CDM perspective, where the lack of regulations in developing countries is a serious barrier. Several initiatives have been commenced and are underway to address deficiencies through regulatory working groups and incorporation of a regulatory component within current and planned CCS projects.

There is an urgent need to put up new complete large-scale CCS projects, combining different technologies and procedures, with the intention of generating further knowledge and experience. While CCS up till now has been explored mainly by large oil companies, for the purpose of EOR, some CCS technologies are commercially available for other large $CO_2$ emitters. A number of projects, pilot and commercial $CO_2$ storage projects are running, under way or proposed. Examples include; the Sleipner project in Norway, where $CO_2$ is injected at a rate of 1 million tonne per year (planned 20 million tons total) in saline aquifers; the RECOPOL project in Poland, where $CO_2$ is injected at a rate of 360 tonne per year (planned 760 tons total) in coal seams for enhanced coal bed methane (ECBM) recovery; and the Gorgon project in Australia potentially 120 million tons at a rate of 3.6 million tons per year is planned to be injected in saline aquifer formations.
These examples and the number of projects in planning demonstrate the high confidence in CCS technologies [1].

# 4. CCS under the Clean Development Mechanism

Potential large point sources of $CO_2$ emissions available for CCS activities exist all over the world, and there is an ongoing debate concerning the inclusion of Carbon Capture and Storage activities under the Clean Development Mechanism. However, unresolved issues such as risk of long term leakage, project boundary and liability issues have remained as barriers to the addition of CCS activities under the Kyoto regime. The process of CCS under CDM needs to consider all interests and stakeholders, such as the need for cost-effective emission reductions, at the same time ensuring this is done in an environmentally secure way. We believe the implementation of strict criteria for storage site selection is an especially important step in order to maintain the environmental integrity of CCS project under CDM. As a regulatory framework falls into place, the implementation of CCS projects globally will be significantly simplified. This must be also be weighted during the discussions of CCS under CDM, as CDM countries usually lack such frameworks and national laws; these are also the countries in the most need of assistance towards achieving sustainable development.

While there are several different kinds of storage projects, the focus of the CDM discussion is on geological storage. Another option for $CO_2$ storage is in coal seams, especially when $CO_2$ is injected into coal seams with the purpose to displace methane, thereby enhancing coal bed methane (CBM) recovery. However, our knowledge of this storage option is limited, and consequently, such activities are not yet ready to be considered under the CDM, but should be further explored for future potential. We also consider, along with most experts, oceanic storage to be far too environmentally unsafe.

The current global energy situation, where the largest share of the world's energy need is covered through oil-powered heating electrical stations and coal, is far from sustainable, and in poor and developing countries, the use of coal is rapidly increasing, as coal is cheap and abundant. According to a recent MIT study [4] CCS is a critical enabling technology as the coal use in poor countries could be doubled and about twice that of rich countries by 2030.

Consequently, the use of environmentally sustainable green technologies and emission reduction technologies like CCS needs to be scaled up and heavily promoted in developing countries within a short timeframe. In addition, there is a need to address equity issues associated with climate change. The Kyoto Protocol's Clean Development Mechanism can play a significant role as a financial incentive for CCS projects in developing countries and should be strategically utilized to effectively support such projects and the subsequent technology transfer. There is a high financial threshold for CCS projects, consequently little incentive for developing countries to undergo such projects. These countries also lack infrastructure, know-how and the necessary regulatory system. CDM provides a financial incentive, thus contributing to an increase of such projects in countries where the potential for large-scale emission reduction through CCS is high.

It is important to consider how CCS activities fulfil the CDM principle of contribution to host country sustainable development, keeping in mind it's the host countries prerogative to decide on these criteria. We believe CCS can be an important contributor to sustainable development in that CCS can:

- Be a bridging solution until long-term alternatives such as renewable energy sources are further developed
- Secure a more sustainable use of a fossil energy source
- Assist developing countries into taking more efficient action on emissions
- Assists developing countries in electrification and increased standard of living
- Contribute to infrastructural build-up and new employment.
- Lead to important technology transfer to developing countries

The detrimental effects global warming will have in developing countries must be kept in mind during this discussion; CCS should not be easily dismissed considering the large scale emission reduction potential of these technologies. To include CCS under CDM, it is understood that it needs to be made sure that CCS is an environmentally safe and sound (technology) as per Decision 17CP.7 in the Kyoto protocol (Article 4, paragraph 5 of the Convention and Article 10). As CCS projects have been happening for the last 30-40 years, this should be considered long enough to prove these projects can be environmentally safe, under the right conditions.

Under the Marrakech Accords, a CDM project is additional if "*anthropogenic emissions of greenhouse gases by sources are reduced below those that would have occurred in the absence of the registered CDM project activity*" ( see www.unfccc.int/cdm). The Additionality criterion must be fulfilled for any CDM project. Without the financial incentive of project income stream from the sale of carbon credits, CCS projects are very rarely financially viable (financial additionality). Enhanced Oil Recovery is in some cases profitable, but in CDM countries, this is not a common activity, and while the financial barrier is less for such projects, other barriers e.g. technological barriers or lack of infrastructure is still in place. However, EOR should undergo a stringent additionality analysis to ensure financial additionality in particular. In general, a barrier test, test for use of BAT and common practice analysis can be utilized for CCS projects as for any CDM projects.

We believe it is very important that Certified Emission Reduction units (CERs) from CCS projects are considered as environmentally legitimate as CERs from other CDM activities. While Certified Emission Reduction (CERs) units from the separate CCS project activities would be fairly straightforward to estimate under a CDM methodology, long term seepage emissions are more complicated. As the risk of seepage both short term and long term is a function of excellent and careful site-selection and project management, the implementation of criteria securing this will also ensure environmental legitimacy of these CERs. CERs should not be devalued in the market due to lack of public knowledge of the environmental security of CCS projects.

Independent risk assessment and verification of CCS projects is a critical and necessary factor for the legitimacy of such projects under the CDM and in general. This should be carried out as per the CDM rules and modalities through the Designated Operational Entity (DOE), who should be required to have the necessary know-how of such projects. However, an obstacle is that the required technology insight, verification methodology and protocols are generally not available from current suppliers of accredited verification of greenhouse gas emissions reductions (1). There is also insufficient knowledge about the methodologies of risk assessment involved in geological storage of $CO_2$. In general there is a need for increasing the knowledge with regard to risk assessment methodologies for geological storage of $CO_2$ and to this extent it is important to document and prepare information material that can be used as a reference for wider distribution, and for incorporation into CDM rules and modalities for CCS project activities.

Finally, permanence is a central aspect of CCS under CDM. Seepage, storage site selection criteria, storage methods as well as prevention of accidents and accountability are all aspects related to permanence. The most essential way to ensure permanence is through proper and stringent site selection criteria, specifically designed to ensure any potential long term risk of seepage is addressed.

In conclusion, Bellona believes that the following principles should guide the further consideration of including CCS activities under the CDM:

- All projects need to be in line with the objectives of the CDM, such as contributing to sustainable development based on host Party's guidelines, and reduce GHG emissions
- Stringent and specific site selection criteria ensuring environmental integrity
- A holistic assessment of environmental impacts, such as risk of seepage and other impacts on the surrounding environment
- The projects must comply with national laws and regulations, as well as multilateral agreements.

## 5. UNFCCC Call for input

The CDM executive board considered the option of CCS as CDM activities at its 22nd meeting, and to obtain further information and inputs on project boundary, leakage and permanence, a workshop was requested from the Conference of the Parties (COP) serving as the Meeting of the Parties (MOP) in 2005. This workshop took place in May 2006, in conjunction with the 24th session of the Subsidiary Body for Scientific and Technological Advice (SBSTA). Several organisations and parties to the Kyoto Protocol provided submissions, promoting the discussion on these issues.

COP/MOP2 was subsequently given recommendations on methodological issues, which were addressed in Nairobi in November 2006. Upon its conclusion, a supplementary invitation was given to IGOs and NGOs to provide to the Secretariat, by 31 May 2007 information addressing the following issues:

a) Long-term physical leakage (seepage) levels of risks and uncertainty;
b) Project boundary issues (such as reservoirs in international waters, several projects using one reservoir) and projects involving more than one country (projects that cross national boundaries);
c) Long-term responsibility for monitoring the reservoir and any remediation measures that may be necessary after the end of the crediting period;
d) Long-term liability for storage sites;
e) Accounting options for any long-term seepage from reservoirs;
f) Criteria and steps for the selection of suitable storage sites with respect to the potential for release of greenhouse gases;
g) Potential leakage paths and site characteristics and monitoring methodologies for physical leakage (seepage) from the storage site and related infrastructure for example, transportation;
h) Operation of reservoirs (for example, well-sealing and abandonment procedures), dynamics of carbon dioxide distribution within the reservoir and remediation issues;
i) Any other relevant matters, including environmental impacts

## a) Long-term physical leakage (seepage) levels of risks and uncertainty;

It is important to separate between leakage defined under the CDM as "*the net change of anthropogenic emissions by sources of greenhouse gases which occurs outside the project boundary, and which is measurable and attributable to the CDM project activity*" (UFCCC/KP/CMP/2005/8/Add.1, page 17, para. 51) and leakage (seepage) of CO2 from the storage site. In this text, seepage referring to $CO_2$ leaking from the storage site discussed.

Seepage from the storage site is of great concern when it comes to CCS projects, be it through wells (injection and/or abandoned), through fractures and faults or through the overlying cap rock. The seepage can be either abrupt or gradual. In any case, an assessment of the risks to humans, ecosystems and ultimately the atmosphere is essential to design a mitigation strategy. Therefore Risk Assessment is a step to manage the risks associated to the leakage in the risk management process. This naturally will be integrated into the CDM process, in the Environmental Impact Assessment (EIA), and verified by the DNA (and the Environmental Agency) and the DOEs, ensuring these have the necessary competence.

The IPCC Special Report on Carbon dioxide and Capture in 2005 [1] indicate that the level of seepage for $CO_2$ storage sites will be at probability of 1% or less seepage after 1000 years. We believe this is an acceptable level considering the alternative, which is 100% escape, following the non-implementation of CCS, where the $CO_2$ is emitted directly into the atmosphere. It should also be expected that following the continuous technological progress and subsequent implementation in the project, uncertainty will be reduced, and long-term sustainability will be ensured.

The key to reduce levels of risk and uncertainty, both short term and long term is a stringent site selection criteria regime. For well selected and managed geological storage sites, the risk levels are comparable to that of other projects already implemented under CDM. Storage projects, e.g. the Sleipner project, implemented over the last 30 years, confirm that such projects can happen without seepage. In addition, we believe the levels of risks are acceptable when considering the significant mitigation potential of these projects, especially in terms of expected technological progress.

In the long term, with the right selection of site, the majority of the $CO_2$ will be gradually immobilized by various trapping mechanisms and could be retained for thousands of years [5].

### b) Project boundary issues (such as reservoirs in international waters, several projects using one reservoir) and projects involving more than one country (projects that cross national boundaries);

The potential storage sites or project areas of CCS project often cross country boundaries. In addition, simulation has shown that the areal extent of a plume of $CO_2$ injected can reach approximately 100 km2 [6] and may grow after injection ceases. The approach to dealing with this issue will vary, depending on the legal framework for ownership of subsurface pore space and the liability. In Europe, for example, pore space is owned by the State and, therefore, utilization is addressed in the licensing process. In the United States, on the other hand, the determination of subsurface property rights on non-federal lands will vary according to state jurisdiction[7].

The issue of access and property rights is a question of national and international laws. In national law, the question is whether reservoirs and aquifers are subject to state ownership, or whether they may be used freely for this purpose by any legal subject. In Norway, the right to use aquifers and reservoirs for petroleum activities is regulated by the Petroleum Act [8]. According to this Act the State has the property right to underground petroleum resources on the continental shelf and the exclusive right to exploitation of these resources. As owner, the State may regulate the use of petroleum reservoirs, and aquifers for either pure deposit of $CO_2$ or injection of $CO_2$ to enhance oil recovery [9]. There is a need for developing countries (CDM countries) to implement similar regulations to ease project implementation.

A relevant case is the ongoing injection of $CO_2$ from the Sleipner Gas Field in Norway. Reservoir formations are used “for the sole purpose of disposal of $CO_2$ that is not a product from petroleum activities” on the Norwegian continental shelf, where exploitation is covered by the scope of application within the Act for the Continental Shelf [10] in lieu of the Petroleum Act [9]. The

Continental Shelf Act covers scientific research and exploration, and exploitation of underground natural resources other than petroleum, in internal Norwegian waters, the territorial sea and on the continental shelf. According to section 2 of the Act, the State has the right to such "underground natural resources" and the quoted statement is interpreted as covering aquifers and reservoirs for use as $CO_2$ deposit [9]. This means that the state has the exclusive right to such use, to control such use and to issue necessary regulations. In international law, the question is if the coastal state has sovereign and exclusive rights to use the underground for $CO_2$ injection purposes. This issue is regulated by the UN Convention of the Law of the Sea [11]. According to this Convention, it has been concluded that Norway has sovereign rights to use underground aquifers and reservoirs on the continental shelf and in the extended economic zone (EEZ) for injection of $CO_2$ for both deposit purposes and enhanced oil recovery [9]. However, as many oil and gas reservoirs including aquifers in the continental shelf are shared with neighbouring countries, Norway can not unilaterally decide to use such reservoirs and aquifers for $CO_2$ injection without an agreement among the parties.

Most of the unresolved issues related to access and property rights apply to onshore projects and because very little case law exists for property rights for onshore CCS projects, access and property rights have typically been determined on a case-by case basis [2]. Many offshore projects are under the purview of international treaties, where regulatory frameworks are in the process of being developed. Since property rights for CCS are still a new issue, and standards for addressing this are not clearly defined, it is difficult to determine property rights in the long term. Clear titles and transferable rights would ensure a regularized operating environment and establish the chain of liability and responsibility in the event of $CO_2$ leakage, migration, or other problems [2].

For CDM projects, it needs to be considered how the project should be approved; as more than one DNA will be involved (also depending on whether the countries have ratified the Kyoto Protocol), and how seepage (for e.g. National GHG inventories) and liability should be treated. For CDM projects crossing boundaries, both international and national regulations, as well as an agreement between neighbouring states needs to be in place. In order to simplify under the CDM, previous suggestions of initially only allowing projects taking place within national boundaries could be appropriate; especially considering long term monitoring responsibility and liability aspects.

## c) Long-term responsibility for monitoring the reservoir and any remediation measures that may be necessary after the end of the crediting period;

Monitoring and modelling are key tools in understanding the complete reservoir performance, both short term and long term. There are presently no established general guidelines for long term monitoring, including who should be responsible and for how long the site is going to be monitored. The discussion regarding CDM monitoring procedures for CCS projects has, however, been fairly elaborate. In general, for any regulatory or legal framework, standards for the measurement, monitoring, and verification (MMV) of injected $CO_2$ are crucial, because they provide for the collection of vital data on containment, reactivity of $CO_2$ with surrounding well materials, seismic activity, leakage, and long-term storage [2]. These are necessary for input to repeated model simulations, risk assessment to ensure that the $CO_2$ behaves as expected or possibly revise the operation plans or start preventive remediation (mitigation strategy). Observation wells are essential and can play key role for MMV of injected $CO_2$.

MMV is still handled on a case-by-case basis and none of the existing projects, including Sleipner, specify the length of time that monitoring will be required or who will be responsible for monitoring in the long-term which addresses one of the major gaps in laying out the legal framework. Considering that CCS projects are designed to last for centuries, it is also difficult to set up MMV (measuring/monitoring/verification) for such long periods of time, but it is known that in mining operations and underground works such as tunnels in copper and other mines have often been left behind, after careful remediation of the site. Water draining in to these structures cause corrosion and polluted water can enter the nature in principle without limitation in time as $CO_2$ storage. Therefore the same existing national rules and regulations which govern these activities can with modifications be adapted to $CO_2$ storage activities [7].

An example of long term responsibility is the Gorgon project where the project developers and the Western Australian Department of Industry and Resources have developed a set of site closure criteria that include a requirement for the project developers to show that the site is safe [26]. The government places the burden of proving long-term safety on the project developers and reduces some of the risk to the government of taking over long-term stewardship of the storage site and the injected $CO_2$. However, the Australian guiding principles have not yet developed guidelines for how the government should monitor and take care of the site in the long term, indicating the difficulty in handling such issues. This is partly due to lack in the definition of the term "long-term". We advocate that long-term should be defined as the time after the operational stage (crediting period/short-term) with certain years after closure based on outputs from performance prediction. [7]

Remediation measures in the event of seepage at operational phase, include halting the injection process, reducing pressure or use of cement to close fractures. If seepage is through undetected fractures and faults or abandoned wells, the injected $CO_2$ can also be withdrawn and re-injected in another site. This means that adjacent well characterized sites need to be in place. After operational phase, cement or withdrawal of $CO_2$ is possible.

In general, we propose to establish a regulatory framework that entail MMV based on performance modelling coupled with risk assessment approach for both the short-term (life span of the project) and long term (certain years after closure) periods. Existing MMV procedures are site-specific, which shows the difficulty of developing a single framework with a uniform set of requirements for a CDM methodology, thus general guidelines should be set up. The monitoring plan laid out in the Project Design Document of the project naturally needs to ensure long term responsibility for monitoring and remediation measures after the crediting period ends. In terms of responsibility, the project developer should be responsible for monitoring the reservoir as well as handle any remediation measures during the CDM project crediting period. In a long term perspective, national government(s) should take over this responsibility, and be legally bound to fulfil monitoring requirements.

## d) Long-term liability for storage sites;

Liability is one of the most essential regulatory issues facing CCS projects, in general and under the CDM. It will impact the costs of CCS projects and will be crucial in advancing public acceptance of the technologies and processes involved. Property rights influences liability, and must therefore be clearly defined [2] as a first step. Property rights also determine who has or will have access to a project site and are therefore a crucial aspect of any CCS project and must be defined in order to encourage investment and proper regulation of the storage site.

The three main areas of property rights are surface (injection of the $CO_2$), subsurface (reservoir), and the $CO_2$ itself. It is also critical to determine if, when, and how private liability is transferred to the public sector, to establish who determines to whom property rights, public and private methods of acquiring the rights, and how to manage the title of the actual $CO_2$.

Liability issues can be divided into short and long-term, with the preponderance of unresolved liability issues relating to long term storage [2].

Short-term liability: a common liability issue raised in connection with the short-term aspects of CCS projects is operational liability, which refers to the environmental, health, and safety risks associated with capture, transport, and injection of $CO_2$. Operational liability is similar to that already dealt with in the oil and gas industry. Such risks have been successfully managed for decades in the context of enhanced oil recovery and analogous activities [13] and they are therefore easier to manage and plan for, and can be addressed in a regulatory framework and also under the CDM.

Long-term liability requires more urgent regulations. There are three types of liability issues that are relevant for long-term CCS projects: environmental, in situ, and trans-national liability [2]. In the event of any $CO_2$ leakage or migration to the atmosphere, in situ or trans-border, responsibility must be assigned to address any harm caused to the global climate, health and environmental damage to the air, soil, water, and overall ecosystem. It is important to state who is responsible for the mitigation actions. Failure to properly address these issues could lead to negative public perceptions and damaged environmental legitimacy of the CDM.

In the case of $CO_2$ leaking into the atmosphere and causing “environmental liability,” this is probably best addressed as part of a broad climate policy designed to control greenhouse gases [14]. The issues of trans-border liability can be addressed by intergovernmental agreements and international treaties. It is possible that $CO_2$ could leak far from its injection point and storage area, and if that leakage point is in another country or in international waters, a framework for determining which party is liable for clean up, remediation, or loss of resources should be established [15]. This can raise the question of how to determine where local/national liability and international liability differs.

A major issue with long-term liability is the timeframe itself [2]. The term “long-term” may be referenced as the time spanning after the operational stage (short-term). However, it is difficult to decide when the shift from short- to long-term should occur because this can partly depend on the scale of future CCS projects, but for CDM projects, end of crediting period is an apparent solution, even though the project might still be running after this period is over. Under the CDM, it would not make sense to leave project developers with the full long term responsibility for any future seepage that might occur, both because of an uncertainty of the regulatory framework and also because the project developers may not exist in the future. In general, transferring the responsibility from the operator to the State requires specific clarification and this could be built on existing national laws in countries of interest. Also, a basic compliance system needs to be established to assure accountability and proper enforcement in the event of leakage or other damage.

Lessons can be learned from the Gorgon project and the guiding principles in Australia [12] which offer a general framework for organizing and classifying the various phases and activities involved in a CCS project. This again enables more consistency in defining regulations, including when and where to assign ownership and liability and thus can be used to develop an internationally consistent legal frameworks for future CCS projects and provide input to the framework under the CDM.

## e) Accounting options for any long-term seepage from reservoirs;

Physical seepage from a storage site in the future must be accounted for, however this is inherently difficult as specific values for discounting are unavailable, and also due to the possibility of future accidents. However, monitoring tools such as seismic time-lapse methods can play a significant role. For instance at Sleipner, this tool provided an insight into the CO2 plume movement, estimating the rate at which CO2 arrived at the top of the reservoir and the volume of CO2 which the topmost layer was compact [å]. Accurate long term accounting is critical to ensure environmental legitimacy of CCS projects under the CDM. From a general accounting aspect we believe the 2006 Guidelines for National Greenhouse Gas Inventories provide a good basis for accounting CCS $CO_2$ emissions, and should be considered for the methodology.

While reservoir seepage occurring during the crediting period is fairly straightforward dealt with in CDM methodologies; any seepage is deducted annually from the baseline, long term seepage presents new issues in terms of project permanence. Options to handle these issues have been presented during previous rounds of CCS under the CDM with suggestions from e.g. the IETA, and will not be further dealt with here.

## f) Criteria and steps for the selection of suitable storage sites with respect to the potential for release of greenhouse gases;

The security of carbon dioxide storage in geological formations depends on careful storage site selection followed by characterization of the selected site. Documentation of the characteristics of any particular storage site will rely on data that have been obtained directly from the storage formation. Today, no standard methodology prescribes how a site must be characterized and chosen, however a lot of criteria have been suggested. Selections are now based on site characterization data made on a site specific basis, choosing those data sets that will be most valuable in that particular geological setting [1].

Appropriate methods for the selection of a site are the most effective means of reducing any potential risks over the long term. Storage requirements for storing $CO_2$ in geological formations must be rigorous and include; adequate porosity and thickness (for storage capacity) and permeability (for injectivity); a satisfactory sealing caprock or confining unit and; a sufficiently stable geological environment to avoid compromising the integrity of the storage site [16].

A challenge is to collect the necessary site data, thus, during site selection; it needs to be ensured that high quality information is provided on:

- Reservoir structure and thickness (from seismic studies)
- Estimated storage capacity and accurate determination of thickness, porosity and permeability of the storage formation
- Physical properties and caprock estimates (sealing capacity)
- Faults and fractures (should be mapped in detail)
- Microseismic studies
- Any abandoned wells in the area that can compromise the storage integrity of the site (should be identified or avoided during the site selection)

However much data collected; there will always be some geological uncertainties left. Knowledge gaps that cannot be covered by the data must be addressed, as they can create errors in processing and interpreting reservoir data. An important question is thus how to handle such risks in general and under the CDM.

Technical risks associated with each storage site must be determined at the beginning of a project and subsequently managed. For the accurate prediction of the behaviour of injected $CO_2$ and hence its migration and long-term fate in the deep sub-surface in different geological formations, standardisation of modelling techniques is another challenge which needs to be considered. The results will influence among others the selection and location of monitoring techniques as seismic and monitoring wells, design and duration of monitoring and verification requirements for the proposed storage site [16].

According to the 2005 IPCC Special Report on Carbon Dioxide and Storage CCS activities would have similar risks in terms of health, safety and environment as current activities such as natural gas storage, EOR and deep underground disposal of acid gas [1]. This is however contingent on the appropriate selection of storage site, a solid monitoring and regulatory system in place, as well as remediation methods to stop and control any accidental release of $CO_2$. All CCS project under CDM must undergo a thorough site characterization as per laid down guidelines, and this must be documented in the PDD. Criteria for selection of suitable storage sites should be subject to general guidelines from the EB and laid down in the monitoring methodology. Through these general rules, it must be ensured that site-specific requirements are met.

## g) Potential leakage paths and site characteristics and monitoring methodologies for physical leakage (seepage) from the storage site and related infrastructure for example, transportation;

For any CCS project, it is necessary to identify any expected seepage paths, timing and amounts of leakage for different sites through adopting appropriate models related to leakage, such as forward model and reservoir simulations. As reservoirs generally cover very large geographical areas, 100% monitoring is very complicated. Thus, weak-spots must be identified and monitoring put up in the most risky areas. Seepage can occur during pipeline transportation, the injection phase or the containment phase and excellent storage site management is the best insurance for minimizing seepage.

High-quality monitoring is crucial not only to discover possible seepage, but also to ensure the $CO_2$ behaves as expected. To date, there are several different general monitoring methods under development for both subsurface and surface monitoring that should be combined for optimal results. Surface monitoring include; Infra-red laser gas analysis; Soil gas or surface water analyses; Satellite or airborne hyperspectral imaging or microbiological monitoring. In addition, subsurface monitoring methods include; active or passive seismics; gravity surveys or electrical methods.

The monitoring tools can vary from site to site (e.g. seismic or geochemical) but the framework needs to ensure consistency and uniformity. An example is the Sleipner project, which has employed 3D and 4D seismic monitoring techniques, as well as time-lapse gravimetry throughout the project, and the operator (Statoil) is continuing to carry out the activity by using the seismic surveying. The work has demonstrated that the injected $CO_2$ is well monitored with no leakages from the geological storage reservoir. The IPCC 2006 Guidelines for determining seepage are useful to set up monitoring methodologies. It must be ensured that site-specific needs are met.

## h) Operation of reservoirs (for example, well-sealing and abandonment procedures), dynamics of carbon dioxide distribution within the reservoir and remediation issues;

Computer simulation has a key role in the design, operation and monitoring of field projects for underground injection of $CO_2$. Simulations of the long-term distribution of $CO_2$ in the subsurface are important for the design of cost-effective monitoring programmes because the results will influence the location of monitoring wells, if suitable, and the frequency of repeat measurements, such as for seismic, soil gas or water chemistry [4]. However, the principal difficulty is that the complex geological models on which the simulation models are subject to considerable uncertainties, resulting both from uncertainties in data interpretation and, in some cases, sparse data sets and associated interpolations in which the models are based. Moreover, predictions of the long-term distribution of injected $CO_2$, including the effects of geochemical reactions, cannot be directly validated on a field scale because these reactions may take hundreds to thousands of years. [5]

In this connection an analysis of the risks associated to models, performance predictions and the long-term integrity of the storage site will be a necessity. Risk assessment should thus be aimed at identifying and quantifying the potential risks and should be an integral element of risk-management activities. A risk assessment should include spanning site selection, site characterization, storage system design, monitoring and remediation [1]. Classification of the potential risks with respect to likelihood, spatial scale and time scale with respect to each risk receptor (humans, environmental media and ecosystems) should be incorporated in regulations governing $CO_2$ storage in geological formations with adaptability to new information and technology as they become available.

By mapping $CO_2$ behaviour and dynamics, monitoring and remediation measures becomes more accurate. The behaviour of CO2 upon reservoir injection, can be predicted by using a model incorporating the following elements, based on IEA 2003 recommendations [17]

- Main mechanisms which are likely to affect reservoir behaviour.
- Location, depth and extent of potential injection disposal zones.
- List all assumption in regards to permeability, porosity, etc., which were used in the model·
- Location and extent of other bottom or lateral bounding formations.·
- Natural fluid flow rates and direction.
- The impact of any density driven flow
- Phase behaviour of fluids and any long-term mass transport phenomena
- Location of existing or abandoned wells or mines in the area that are likely to affect storage of $CO_2$ in the reservoir
- Identification of potential spill points
- Comment on the uncertainty of the model(s) and conduct a sensitivity analysis to test whether it is robust to reasonable variation in the assumptions

The dynamics of carbon dioxide within the reservoir are also important to map; there are several flow and transport mechanisms that control the spread of $CO_2$ [5]:

- Fluid flow (migration) in response te pressure gradients created by the injection process;
- Fluid flow in response to natural hydraulic gradients;
- Buoyancy caused by the density differences between $CO_2$ and the formation fluids;
- Diffusion;
- Dispersion and fingering caused by formation heterogeneities and mobility contrast between $CO_2$ and formation fluid;
- Dissolution into the formation fluid;

- Mineralization
- Pore space (relative permeability) trapping
- Adsorption of $CO_2$ onto organic material

When $CO_2$ is injected into a formation, it displaces saline formation water, oil or gas and then migrates buoyantly upwards, because it is less dense than the formation fluids. When it reaches the top of the formation, it continues to migrate as a separate phase until it is trapped as residual $CO_2$ saturation or in local structural or stratigraphic traps within the sealing formation (physical trapping of $CO_2$). In the longer term, significant quantities of $CO_2$ dissolve in the formation water and then migrate with the groundwater. Carbon dioxide in the subsurface can undergo a sequence of geochemical interactions with the rock and formation, resulting in geochemical trapping. First, when $CO_2$ dissolves in formation water, a process commonly called solubility trapping occurs. The primary benefit of solubility trapping is that once $CO_2$ is dissolved, it no longer exists as a separate phase, thereby eliminating the buoyant forces that drive it upwards. Next, it will form ionic species as the rock dissolves, accompanied by a rise in the pH. Finally, after very long periods of time/geologic time some fraction may be converted to stable carbonate minerals (mineral trapping), the most permanent form of geological storage [1].

### i) Any other relevant matters, including environmental impacts

No additional matters beyond what has already been addressed.

## 6. Conclusion

The IPCC regards CCS as one of the main strategies for reducing $CO_2$ emissions and Bellona's calculations show that CCS has the potential to cut global $CO_2$ emissions by 37% by 2050. The support for CCS activities is strong and increasing, as is the number of projects in planning. Efforts are underway to develop national and international rules and regulations for CCS projects and a consistent effort to address the major unresolved regulatory issues related to CCS, such as long-term stewardship of the stored $CO_2$, is required for the rapid implementation of the technology.

An internationally consistent guiding framework, that address challenges and deals with any long-term risks can facilitate a successful inclusion of CCS under the CDM, full-scale deployment of the CCS technology and can build public confidence. Instead of allowing the lack of regulatory framework to be a barrier for CCS under CDM, we believe the inclusion of CCS under CDM can contribute to accelerate the work with defining the proper regulatory framework, in particular in developing countries.

The IPCC target of 50-80% reduction in global GHG emissions by 2050 cannot be reached by energy efficiency and renewable energy alone and emission reductions in developing countries is urgent. It is therefore crucial that CCS technologies through the CDM become available to the developing countries with a strong dependence on fossil fuels, struggling to combine economic growth with environmental sustainability. We also believe that CCS can have additional sustainable development benefits.

Critique against CCS is usually with reference to the safety of $CO_2$ storage. However, all scientific evidence show that $CO_2$ storage is safe provided careful site characterisation and selection. Combining stringent site selection criteria and high-quality monitoring is a thus pre-requisite for CCS projects implemented under the CDM.

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