A Proposal of Regulatory Framework for Carbon Dioxide Storage in Geological Formations

Semere Solomon[1], Beate Kristiansen[1], Aage Stangeland[1], Tore A. Torp[2], Olav Kårstad[2]

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[1] The Bellona Foundation, P.O.Box 2141, Grünerløkka, Nordre gate 2, N-0505 Oslo, Norway
[2] Statoil Research Centre, NO-7005 Trondheim, Norway

Abstract

CO_2 capture and storage (CCS) is getting attention as a viable option to mitigate climate change. The success of CCS as a greenhouse gas mitigation strategy depends on the regulatory framework established to govern its deployment. Several initiatives have been undertaken and are underway to address deficiencies through regulatory working groups and by incorporating a regulatory component within current and planned CCS projects. This paper is part of the efforts initiated by the International Risk Governance Council (IRGC) which outlines the attributes that an effective regulatory regime for CCS should posses.

Thorough examination of the national and international laws to determine how they should be adjusted to clarify the definition of CO_2 including impurities is necessary. As access and property right is the issue of national and international laws and also influences liability, they must be clearly defined. Monitoring and Verification plays an important role in outlining the legal frameworks for CCS and should be 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. We advocate that long-term be defined as the time after the operational stage (short-term) with certain years after closure based on outputs from performance prediction. There is a need to address especially the long-term liability issues regardless of whether these are environment, in situ, or trans-border. To establish an internationally agreed guiding framework for CCS deployment we propose that legal and regulatory frameworks take into account the technical aspects with respect to the geological storage options including the issues that can arise in geological storage of CO_2. These are specifically site selection, the scale, performance prediction and risk assessment issues as well as mitigation strategies in the events of leakage.

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1. Introduction

CO_2 capture and storage (CCS) is getting attention as a viable option to mitigate climate change. The success of carbon capture and storage as a greenhouse gas mitigation strategy depends on the regulatory framework established to govern its deployment. With a rapid growth of the number and scope of carbon capture and storage (CCS) projects worldwide the lack of a clear, defined legal and regulatory framework in which to operate is of great concern. Several initiatives have been undertaken and are underway to address deficiencies through regulatory working groups and by incorporating a regulatory component within current and planned CCS projects. This essay is part of the efforts initiated by the International Risk Governance Council (IRGC) which outlines the attributes that an effective regulatory regime for CCS should posses.

With the available storage options at hand and given the technical challenges to be considered in a storage site, the issues particularly the site selection, the scale of operation and the risks associated with performance predictions need to be considered when laying out the regulatory frameworks for CCS operations. Regulations that take into account the technical barriers and issues are needed specifically that 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. A regulatory framework that encourages good practice and incorporates our evolving understanding of risk and its management (mitigation strategy) could promote public trust and widespread deployment of the CCS technology as potential emission reduction option.

2. Overview of Geological Storage

Geological storage of CO_2 can be undertaken in a variety of geological settings in sedimentary basins. Within these basins, oil fields, depleted gas fields, deep coal seams and saline formations are all possible storage formations both onshore and offshore.

Oil and gas fields storage include depleted reservoirs for pure storage, or for the purpose of enhanced resource recovery such as enhanced oil recovery (EOR) and/or enhanced gas recovery (EGR). Although the geological structures and physical properties of most oil and gas fields have been extensively studied and characterized, of great concern are abandoned wells in many mature fields. Plugging of abandoned wells in many mature fields which began many decades ago were not constructed with due considerations that the fields could be used to contain a reactive and potentially buoyant fluid such as CO_2. Therefore, the condition of wells penetrating the caprock must be assessed [1]. In some areas of the world, even locating the wells may be difficult and caprock integrity may need to be confirmed. The capacity of a reservoir will be limited by the need to avoid exceeding pressures that damage the caprock [2] and [3].

Saline formations are widespread and contain enormous quantities of water, but are unsuitable for agriculture or human consumption. They are in many cases not well characterized as the oil and gas fields and hence CO_2 storage scheme in such formations requires careful site characterization. Typical problems are that the aquifer boundaries are open and presence of abandoned wells which could pose threats for the long-term storage integrity. A third option for CO_2 storage is 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 in this storage option is limited compared to other options. Major problems are: lack of complete knowledge in the process of CO_2 trapping in coals, coal plasticization or softening, coal swelling, reaction between the injected CO_2 and coal, and the likely future fate of a coal seam [4].

3. Issues in geological storage of CO_2

3.1 Site Selection

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. Instead, selections based on site characterization data are made on a site-specific basis, choosing those data sets that will be most valuable in the particular geological setting.

Appropriate methods for the selection of a site are the most effective means of reducing any potential risks over the long-term. At this stage the technical risk associated with each storage site must be determined at the beginning of a project and subsequently managed. First challenge is to collect the necessary site data. However, how much data collected there will always be some geological uncertainties left. 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. An internationally consistent guiding framework, that can address these challenges and that deals with any long-term risks can facilitate full-scale deployment of the CCS technology and can build public confidence.

3.2 The Scale of Geological Storage Projects

A number of pilot and commercial CO_2 storage projects are under way or proposed. The projects are already injecting or planning to inject CO_2 into a variety of formations, such as aquifers, depleted hydrocarbon reservoirs, coal seams, and saline formations on a range of scales and injection rates. For instance at the RECOPOL project in Poland 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, which is typical of a small-scale project. At the Sleipner project in Norway CO_2 is injected at a rate of 1 million tonne per year (planned 20 million tons total) in saline aquifers, which may be considered a medium-scale project. Similarly at 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 which may be a large-scale project. All these projects mentioned together with the number of CO_2 capture and storage projects which have already been announced demonstrate the confidence in this technology [4]. However, these projects also raise important issues such as the scale and life span of the projects which are critical with regard to site selection, monitoring and verification procedures and mitigation actions as well as the duration required for monitoring and verification and hence outlining the guidelines for regulatory frameworks.

The effects of scale should be considered in outlining the regulatory frameworks for CCS projects. For instance, simulations have shown that the areal extent of a plume of CO_2 injected can reach approximately 100 km^2 [5] 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. In most jurisdictions, the surface owner is entitled to exclusive possession of the space formerly occupied by the subsurface minerals when the minerals are exhausted, that is, the ‘pore space’ [6]. In the example mentioned 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 to the damages incurred need to be established. This can raise the question on how to determine where local/national liability and international liability differs.

3.3 Performance Prediction and Risk Assessment

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, a mechanism known as 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 [4].

Computer simulation has a key role in the design and operation 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 based 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.

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 requirement. Risk assessment should thus be aimed at identifying and quantifying the potential risks and should be an integral element of risk-management activities. Risk assessment should include spanning site selection, site characterization, storage system design, monitoring and remediation [4]. 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 new regulations governing CO_2 storage in geological formations with adaptability to new information and technology as they become available.

4. Regulatory Frameworks

4.1 Definition/Classification of Carbon Dioxide (CO_2)

To date there is a lack of consistent and clear definition or classification of CO_2. In general, the stored CO_2 can either be classified as an industrial product or as a waste product. The definition of CO_2 and the process by which it is stored is crucial for determining the type and jurisdiction of the regulations covering CCS activities and this distinction is important because industrial projects typically are subject to less stringent environmental regulations than waste disposal projects [7]. Also 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 [4]. Some contaminants in the CO_2 stream (e.g. SO_x, NO_x, H_2S) may require classification as hazardous, imposing different requirements for injection and disposal than if the stream were pure [8]. Regulatory framework must state the allowed concentration of impurities and the lowest allowed CO_2 concentration.

How CO_2 is classified also determines its legality and treatment under international treaties and national laws and regulations [7]. Classification of CO_2 as “waste” or industrial “by product” is covered under the London [9] and OSPAR [10] Conventions because the texts state “waste or other matters”. According to the Legal Experts [11], whether CO_2 is “waste” or "other matter" is thus not essential and the Basel Convention [12] only applies to "hazardous waste" and CO_2 is not a "hazardous waste". Under the EU Directives concerning waste and water [13], the Basel Convention becomes presumably relevant. Current projects are allowed as industrial storage or enhanced resource recovery projects under the marine treaties [9, 10, 12, 14 and 15]. Typical example is the Sleipner project [16] in Norway where the CO_2 extracted is considered the result of industrial activities, it has generally been accepted to be allowed under the international marine pollution treaties. The treaties were established before the emergence of CCS as a major option for reducing CO_2 emissions, and so a new framework may be needed to deal specifically with CCS projects, including those offshore projects, such as Sleipner, that do not include enhanced resource recovery [7]. However, recently the London Protocol [14], parties finalised a discussion by amending the annex, stating that CO2 storage under the sea bottom is explicitly allowed with some limitations. The limitation is expressed as no matters are allowed to be added for deposition, after the prime CO_2 capture process. Further technical clarification is now under preparation. The OSPAR parties have for some time been through a similar discussion and will probably make a decision by end of 2007...

4.2 Access and property rights

Property rights often 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 properly regulate the storage site. The three main areas of property rights are surface (injection of the CO_2), sub-surface (reservoir), and the CO_2 itself and because the definition of property rights also influences liability, they must be clearly defined [7]. It is also critical to determine if, when, and how private liability is transferred to the public sector, 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.

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 [17]. 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 [18]. The most relevant case is the ongoing injection of CO_2 from the Sleipner Gas Field. When 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, then exploitation is covered by the scope of application within the Act for the Continental Shelf [19] in lieu of the Petroleum Act [18]. 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 [18]. 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 [15]. 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 [18]. 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 [7]. Many offshore projects are under the purview of international treaties, where regulatory frameworks are already in the process of being developed. Since property rights for CCS are still a new issue, and standards for addressing this issue are not clearly defined, making it 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 [7].

4.3 Intellectual property rights (IPR)

Intellectual property rights (IPR) applies to the various legal entitlements which attach to certain types of information, ideas, or other forms of innovations. Although the holder of this legal entitlement is generally entitled to exercise various exclusive rights in relation to the subject matter of the IPR, these laws are becoming increasingly harmonised through the effects of international treaties such as the 1994 World Trade Organization (WTO) Agreement on Trade-Related Aspects of Intellectual Property Rights (TRIPs) [20].

IPR issues are critical when it comes to the transfer of technology, especially in the absence of a stringent regulatory framework. A robust IPR regime in developing countries is crucial for encouraging developed countries to invest in CCS technologies for transfer and deployment in developing countries. IPR has been addressed through the Consortium Agreement made up between all partners of the Sleipner project. The European Commission, through its 6th Framework Program for Research and Development, has a set of rules to be followed, but the Sleipner partners have surpassed these rules in that they have granted themselves broad, worldwide, and irrevocable rights to use the results of the Sleipner project [7]. Therefore there is a need to develop a consistent CCS-specific IPR legal regime that include modelling, measuring and monitoring instruments, and other technological methods.

4.4 Monitoring and verification requirements

Standards for the measurement, monitoring, and verification (MMV) of injected CO_2 are crucial to any regulatory or legal framework for CCS 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 [7]. 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). In some cases observation wells are essential for MMV of injected CO_2. Existing MMV procedures are site-specific and this makes it difficult to develop a single framework with a uniform set of requirements. 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. There is a need to define the term "long-term" and the definition could be based on the output of the performance prediction. The monitoring tools can vary from site to site (e.g. seismic or geochemical) but the framework is thought to create consistency and uniformity.

Sleipner has employed both 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 demonstrated that the injected CO_2 is well monitored with no leakages from the geological storage reservoir. Monitoring and modelling proved to be key tools in understanding the whole reservoir performance. However, there are no established guidelines for the monitoring in the long-term, including who should be doing the monitoring and for how long the site is going to be monitored.

4.5 Liability

Liability is one of the most essential regulatory issues facing CCS projects. It will impact the costs of CCS projects and will be crucial in advancing public acceptance of the technologies and processes involved. Liability issues can be divided into short- and long-term, with the preponderance of unresolved liability issues relating to long-term storage [7].

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 [21] and they are therefore easier to manage and plan for, and could be addressed in a regulatory framework relatively quickly.

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 [7]. 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 also important to state who is responsible for the mitigation actions. Failure to properly address these issues could lead to negative public perceptions.

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 [22]. 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 [23].

A major issue with long-term liability is simply the timeframe itself [7]. The term "long-term" may be referenced as the time spanning after the operational stage (short-term). However, it is difficult to set when the shift from short- to long-term should occur because this can partly depend on the scale of future CCS projects. Considering that CCS projects are designed to last for centuries, it may be difficult to set up MMV 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 are used to be 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. Transferring the responsibility from the operator to the State at the end of the injection period requires specific clarification and this can be built on existing national laws in countries of interest. Also, a basic compliance system should be established to assure accountability and proper enforcement in the event of leakage or other damage. Determining responsibility for cost coverage is crucial, and several options are proposed [7] and [21].

In Norway the Pollution Control Act [24] has special rules on liability for environmental damage, based on strict and severe liability for the operator of the installation or activity that causes the damage. CO_2 injection/storage is in principle included in the law as long as there is leakage from the storage formation which brings hazard or pollution as all any other activities which are threat for pollution. Both the Mining Act [25] and the Petroleum Act [17] also put that the operator should clean up, secure life of people and nature for unlimited time, and must have the authorities/governments approval before the operator leaves the place. These rules, however, do not apply to damages caused by the injection of CO_2 and should be considered for amendments to include both offshore and onshore activities.

5. Discussions and conclusion

Efforts are underway in the development of national and international rules and regulations for CCS projects [23] and [26]. 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 rapid implementation of the technology. A process is already started in several countries and regions under cooperation, e.g. Australia, Canada and EU to thoroughly examine national and international laws to determine how they should be adjusted in countries of interest to clarify the definition of CO_2 including impurities if any and the status of CCS technologies and their use. As access and property right is the issue of national and international laws and also influences liability, they must be clearly defined and should be prioritized.

Monitoring and Verification component plays a great role in outlining the legal frameworks for CCS and should be 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. Observation wells are essential and can play key role for MMV of injected CO_2. However, 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. For example in Gorgon project 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 be defined as the time after the operational stage (short-term) with certain years after closure based on outputs from performance prediction.

There is a need to address especially the long-term liability issues regardless of whether these are environment, in situ, or trans-border. The term “long-term” may be referenced as the time spanning after the operational stage (short-term) plus certain years after closure of the site as mentioned earlier. However, it is difficult to set when the shift from short- to long-term should occur because this can partly depend on the scale and life span of future CCS projects. It is difficult also to set up MMV for long periods of time, but there should at least be parameters and guidelines laid down based on performance modelling and risk assessment procedures for both short and long terms. Long-term liability is well addressed under the national laws of Norway [17, 24 and 25]; however, these laws need to be tuned to suit the geological storage of CO_2. Lessons can be learned from the

Gorgon project and the newly released guiding principles in Australia [26] 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. To establish an internationally agreed guiding framework for CCS deployment we propose that legal and regulatory frameworks take into account the technical aspects with respect to the geological storage options including the issues that can arise in geological storage of CO_2 specifically site selection, the scale, and performance prediction and risk assessment issues as well as mitigation strategies in the events of leakage.

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