# Regulatory Aspects of Deep (Geological) $CO_2$ Storage

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## Abstract

With the growth internationally of projects involving deep (geologic) storage of $CO_2$, there has been a recognition that some form of regulatory guidance or control of this developing technology is needed. With this in mind, the IEA Greenhouse Gas R&D Programme commissioned a project to examine key potential regulatory issues associated with the long-term storage of $CO_2$.

Most industry standards and codes relate principally to an operational period for engineering projects of up to several decades, perhaps as much as one hundred years. In contrast, $CO_2$ stored in geological reservoirs will be expected to remain underground for much longer time periods. Thus, the challenge is for any regulatory guidance or control to address the *long-term* framework for $CO_2$ storage, *i.e.* time frames relevant to storage performance as well as to health and safety and environmental consequences.

This paper identifies and discusses regulatory issues that are relevant to a regulatory framework governing the deep geological storage of $CO_2$. These issues, in turn, address two key regulatory drivers associated with long-term $CO_2$ storage: (i) from a greenhouse gas mitigation option perspective, the need to ensure that the $CO_2$ injected underground remains in the storage reservoir or, if some release back to the atmosphere occurs, to ensure that this release can be accounted for; and (ii) from a health, safety and environment perspective, that any migration of $CO_2$ away from the reservoir does not cause any harm, either to humans or to the environment.

In addition, consideration was given to possible existing national and international regulatory frameworks that might be adapted to accommodate CCS projects. Modification of an existing regulatory scheme seems more attractive than the development of an entirely new regulatory system. Thus, this paper considers the appropriateness of existing regulations to cover $CO_2$ storage projects. One example of such legislation features the environmental assessment process that is carried out under its various national formats in Europe as well as in North America.


## 1. Introduction

With the increasing number of "pilot" or relatively small-scale projects to examine or demonstrate the feasibility of deep (geological) storage of $CO_2$ comes the realistic prospect of the large-scale development of carbon capture and storage (CCS) technology as a significant greenhouse gas (GHG) mitigation option. What would help to encourage widespread implementation of this technology is the existence of an effective regulatory framework providing guidance / control of CCS projects. Accordingly, the IEA GHG R&D Programme commissioned a study to examine potential regulatory issues that might need to be addressed within a regulatory regime. This paper outlines the key output from this IEA study. Further details may be obtained in the original report (Stenhouse et al., 2004).

### *1.1 Regulatory Drivers*

Two key drivers need to be addressed in a regulatory framework for CCS projects:

- From the perspective of a GHG mitigation option, regulatory supervision needs to ensure that the $CO_2$ that is injected into a geological storage remains there or, at the very least, needs to ensure that any releases of $CO_2$ back to the atmosphere can be accounted for.
- From the perspective of health, safety and environmental (HSE) concerns, a regulatory framework needs to ensure that any migration of $CO_2$ away from the reservoir does not reach the surface / near-surface environment at a rate sufficient to cause harm to humans or the environment.

Both drivers require effective reservoir storage and clearly, if all of the $CO_2$ remains in the storage reservoir, both concerns will be met. However, the timeframes over which each driver is relevant are potentially different. In this context, the IEA study was concerned only with long-term regulatory issues, i.e. after the operational phase of the CCS project. Thereafter, with respect to GHG mitigation, a timeframe of hundreds of years for the $CO_2$ to remain underground seems appropriate, providing sufficient time for technological advances to achieve a stabilization and reduction of atmospheric $CO_2$ levels. On the other hand, the timeframe over which safety concerns need to be addressed involves thousands of years, essentially for as long as the potential exists for $CO_2$ to be released to the surface/near-surface environment in sufficient quantities to cause a safety problem.

With regard to human safety and negative environmental impacts, the actual timeframe of concern is likely to be site-specific as well as storage-concept specific. For example, the nature of the storage reservoir and storage concept will determine the importance of natural processes to disperse and dilute the $CO_2$. Where $CO_2$ dissolution in an aquifer occurs, the rate of aquifer flow as well as its direction could result in subsequent exsolution of $CO_2$ as the physical and thermodynamic constraints of the fluid change. Irrespective of what processes are important to a particular geological storage project, the regulator must be assured that the long-term outcome of any such project is safe.

Because CCS projects are relatively few at this stage, the experience gained so far is correspondingly small. It is likely that, with more and more projects, our level of understanding and knowledge will grow with experience and that long-term predictions may conclude that the hazard from $CO_2$ is negligible. However, at this stage of technological development, we do not have this level of confidence, although some degree of confidence can be obtained from natural and man-made analogues of geological $CO_2$ storage (Benson et al., 2002).

## 2. Regulatory Issues

Key regulatory issues that were identified are:

- Liability
- Economics
- Subsurface $CO_2$ migration away from the storage reservoir
- Monitoring
- Wellbore integrity
- Record keeping / archival

Some relevant comments are provided below for each issue.

*Liability*: Some aspect of liability is relevant to both regulatory drivers – GHG mitigation and HSE concerns. With regard to GHG mitigation, since storage is aimed at keeping $CO_2$ underground, the potential for liability exists in the form of an economic penalty if $CO_2$ is released back to the atmosphere. If such a situation arises, how should the penalty be determined and for how long should this liability last?

In the context of HSE concerns and associated liability, the relevant legal standards are negligence and strict liability. Given that both of these can be dealt with at regional and national levels, e.g., at the federal and state levels in the USA, there is a need to normalize the potential liability associated with CCS projects to avoid different penalties between local regions. In this respect, the long-term nature of HSE concerns represents a potential impediment to a project's progress. Resolution of such a problem would occur if there were a mechanism in place to allow the transfer of liability to the public sector, provided, of course, that the regulator was assured of long-term safety.

*Economic Aspects of Geological $CO_2$ Storage*:

From the previous section, it is clear that liability and economics are closely linked. In fact, most of the regulatory issues identified are linked in some way to economics, a key driver for the development of CCS projects. In this respect, the regulatory attitude to key phases of a CCS project, notably, site characterization requirements associated with possible permitting, will have a major impact on the overall cost of a project. Thus, while certain basic requirements might be defined for the site characterization phase, *e.g.*, the drilling of at least one borehole and examination of the cuttings obtained, regulatory *guidance* at this stage is preferable to a fully prescriptive approach. On the other hand, operators should be aware that there is likely to be some form of (inverse) relationship between up-front site characterization costs and the level of monitoring that might be required after the operational stage in order to assure the regulator of long-term safety.

Ownership of the reservoir and its pore space is also a potential legal issue with strong economic implications. At the very least, there is a need for a uniform legal treatment of pore space, or at least a definition of ownership in this regard. Ownership rights are important because some form of royalty payment or fee seems appropriate to cover exposure to the liability associated with the storage reservoir.

*Migration of $CO_2$ Away from Storage Reservoir*:

Subsurface migration of $CO_2$ away from the reservoir is not necessarily a problem with respect to safety. In fact, under such circumstances, natural processes (dissolution, advection, dispersion) will act to dilute and disperse the $CO_2$ phase, thereby reducing its hazard potential. Some potential hazard remains however, if the aquifer carrying the $CO_2$ is relatively confined and moves up-dip to significantly lower depth where exsolution of $CO_2$ occurs.

In situations where $CO_2$ migrates away from the reservoir but is not released to the surface, the main regulatory concern is associated with GHG mitigation and the potential need to account for loss of $CO_2$ from the storage reservoir. Whether there *is* a need to account for such $CO_2$ is an issue in itself, since the lack of release to the surface will not impact GHG mitigation. Complications may arise, however, in the case where there are a series of adjacent CCS projects, with the $CO_2$ being injected into the same horizon. Under such circumstances, $CO_2$ migration has the potential to impact adjacent storage areas. From a regulatory perspective, evidence of whether such migration is likely to occur will rely heavily, but not exclusively, on migration modeling.

*Monitoring in Support of Geological $CO_2$ Storage*:

From a regulatory perspective, there are several reasons why monitoring is necessary, or advisable, *viz.*

- To provide confirmation that modeling predictions fall within measurable bounds, thereby adding confidence to those predictions;
- To promote public confidence, by requiring some form of monitoring to demonstrate that there are no, or negligible, releases of $CO_2$ back to the surface;
- To support the accounting of GHG accreditation.

A large number of monitoring techniques are currently available, ranging from surface-based, subsurface, injection zone, and remote sensing techniques (Benson *et al*., 2004). Each technique has its limitations in terms of quantification (accuracy and minimum amount of $CO_2$ that can be detected under field conditions). Given the importance of monitoring in support of GHG accounting, further development of techniques is likely with a view to improving their accuracy. Thus, the regulator needs to be aware of what techniques are available, and what their capabilities are, in order to be able to assess uncertainties in measurements. Importantly, some guidance needs to be given concerning how long to monitor.

*Long-Term Wellbore Integrity*:

Abandoned wells are potentially the weakest part of a geological storage system, particularly with respect to long-term integrity for which no evidence exists beyond several decades. Although the geology may be perfectly adequate to contain the $CO_2$ injected into the storage reservoir, degradation of one or more components of an abandoned well (cement seals, metal casing) may allow the release of some $CO_2$ back to the surface. On the other hand, mitigation of a leaking well is routine practice in the oil&gas industry. Again, the primary difference between standard oil&gas procedures and a CCS project is the extended timeframe over which leakage should be prevented.

For these reasons, the regulator should expect to see in any safety submission careful consideration of the long-term integrity of abandoned well, for example via more robust (with respect to long-term degradation) sealing techniques employed, or from modeling predictions that indicate that long-term integrity of abandoned wells is not a problem because the $CO_2$ injected into the reservoir will disperse within a relatively short time period.

In addition, in some parts of the world, e.g. Alberta and Saskatchewan, there is an abundance of abandoned wells, some of these wells originating from the early days of oil&gas exploration. Thus, while newer wells may be abandoned according to robust sealing technology, the possibility exists of undocumented wells or even an open borehole in the vicinity of a CCS project. Thus, depending on the location of a CCS project, some effort may need to be devoted to identifying the existence of older wellbores in the area and establishing the condition of the seals. Part of this work could be dealt with at the site characterization stage of the project.

Record Keeping / Archival: Good record keeping is necessarily primarily for accounting for GHG accreditation. In addition, knowledge of past CCS projects including the location of abandoned wells, will be important practical information for upcoming CCS projects. In the latter case, for CCS projects that involve the same injection horizon at adjacent geographic locations, data from a previous project might be necessary input for modeling predictions for the newer project.

The basic elements of record keeping and archival over long periods of time (centuries) have been demonstrated throughout history and should not represent a problem for regulators, although it should be recognized that recording media will change with time. As a means of storing relevant project details, the concept of regional databases feeding into a national database is a reasonable one. For contiguous countries, an international database comprising relevant national databases would also be important.

SUMMARY of Regulatory Issues: Table 1 provides a summary of the above regulatory issues and how they relate to the two regulatory drivers discussed in Section 1.2.

## 3. Possible (Adaptable) Regulatory Frameworks – Some Examples

Some recent papers have discussed national and international regulations that are, or could be, applicable to CCS projects (Wilson *et al*., 2003; Ducroux and Bewers, 2004; Wall *et al*., 2004). Here, a few examples of national regulatory frameworks that could be adapted for CCS projects are noted.

In the United States, for example, management of underground fluid injection is carried out under the Environmental Protection Agency's (EPA) Underground Injection and Control (UIC) Program, aimed at protecting public drinking water. The regulations identify five classes of wells, of which Class I wells include the injection of hazardous and non-hazardous industrial wastes, while Class II wells involve primarily the injection of fluids associated with the hydrocarbon industry. Interestingly, Class I wells contain a no-migration standard and a no-migration petition approval process. In order to obtain a no-migration petition, the injected wastes must not impact groundwater or surface water over a period of 10,000 years.

Similarly, in western Canada, the injection of acid gas ($H_2S$, $CO_2$) is a routine procedure. Permitting requirements for such disposal include the specific requirements associated with conventional oil and gas reservoirs, which in turn require a general assessment of the regional geology and hydrogeology to determine the potential for leakage (Bachu and Gunter, 2004a). Specific case histories of acid gas injection are discussed in Bachu and Gunter (2004b).

*Table 1*: Summary of key regulatory issues associated with CCS projects.

| Issue | Regulatory Driver: GHG Mitigation | Regulatory Driver: HSE Concerns |
|---|---|---|
| **Liability** | Penalty for $CO_2$ release back to atmosphere – how to establish penalty? How long does such liability last? | Legal responsibility for HSE impacts: can be interpreted as negligence and strict liability; How long does such liability last? Mechanism for transference to public sector? Liability affects Economics |
| **Economics** | Regulatory attitude to site characterization: flexible or prescriptive? Who owns the reservoir and its pore space? Need for uniformity in legal treatment, legal definition of ownership. Possibility of royalty fees | Ownership affects liability |
| **$CO_2$ migration (sub-surface) away from reservoir** | How to address such migration in terms of GHG accounting? | $CO_2$ migration may eventually lead to release to surface; *may* represent potential hazard |
| **Monitoring** | Primarily to confirm modeling predictions and to account for $CO_2$ storage / releases. How long to monitor? (Probably as long as GHG mitigation is important.) | Primarily public confidence and to confirm modeling predictions. How long to monitor? |
| **Wellbore integrity (long-term)** | Loss of integrity could lead to $CO_2$ releases back to atmosphere, impacting GHG mitigation; long timeframe for consideration | Loss of integrity could lead to $CO_2$ releases back to surface / near-surface environment with associated potential HSE impacts; extended timeframe for consideration |
| **Record keeping / Archival** | Record of project details for accounting purposes and for future project consideration; long timeframe for archival<br>Regional databases feeding into National Database; ==> International Database | Record of abandoned wells; extended timeframe for archival |

With respect to geological $CO_2$ storage, the CRUST (CO2 Reuse through Underground STorage) is underway in the Netherlands, involving the underground storage of $CO_2$. Because the storage is designed to take account of the possible future re-use of the $CO_2$, it is referred to as a '*buffer'* storage project. Prior to starting the project, a project task force carried out a review of the legal implications and existing regulations that might cover the project. This Task Force concluded that a combination of the Mining Act and the Environmental Management Act addressed many of the relevant aspects of a $CO_2$ injection and storage project (Juridische Task Force, 2001). The latter Act contained the requirements for an Environmental Impact Assessment (EIA – see next section).

## 4. Environment Assessment Process

One drawback of the regulatory regimes mentioned in the previous section is that they are country-specific. Ideally, some form of internationally-acceptable scheme would help to unify the treatment of CCS projects in different countries.

Environmental Impact Assessment (EIA) was introduced in the United States as an action-forcing mechanism in the National Environmental Policy Act (NEPA) on January 1, 1970. Since then, EIA has been introduced around the world in many different ways. For example, in 1985, the European Union (EU) introduced EIA legislation (Directive 85/337/EEC) that was later amended (Directive 97/11/EEC, 1997). Member States were required to transpose the amended EIA Directive no later than 14 March 1999. Where the EA process is applied to individual projects, it is called Environmental Impact Assessment (EIA). Where EA is applied to programs and policies, it is called Strategic Environmental Assessment.

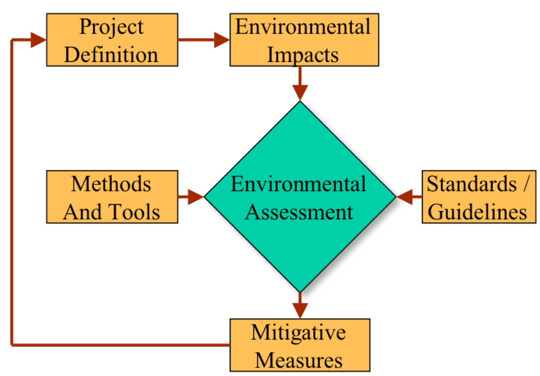
The EIA procedure ensures that environmental consequences of projects are identified and assessed prior to authorization being given. In the EU, certain types of projects have been identified, for which an EIA is mandatory (Annex I projects) or an EIA *may* be required (Annex II projects). Thus, in the latter case, there is some flexibility, the EIA depending on an initial screening of potential impacts.

The generic approach to a project involves a series of steps:

- Project proposal explaining the nature of the project and the identification of possible impacts.
- Screening by the regulator to determine whether an EIA is required.
- Scoping of impacts to establish which ones should be examined further.
- Prediction of consequences of these impacts.
- Possible mitigation measures that could be taken to reduce impacts.
- Submission of Environmental Impact Statement (EIS).
- Period of review by regulator and stakeholders. This period allows comment by the general public and in some cases, a public hearing may be necessary.
- Final EIS submission.
- Decision-making.
- Evaluation and monitoring.

*Figure 1* shows the World Bank template for the EA/EIA process, which matches the key steps of the generic procedure fairly closely. In the diagram, the Standards/Guidelines shown are intended to be used as a measure for comparison with the predicted consequences, in order to support the decision-making process.

*Figure 1*: World Bank template for EA/EIA process.




One advantage of the EIA process is that EIA legislation already exists in different countries, and the requirements identified in such legislation are tending towards convergence. In the EC in particular, as stated previously, Member States were required to enact, within a certain timeframe, national EIA legislation that was compatible with the EC Directives of 1985 (85/337/EEC) and 1997 (97/11/EEC). Indeed, the specific rationale for the latter EC Directive was to minimize differences and harmonize requirements between countries. In addition, there is a degree of flexibility in terms of the level of effort involved in the assessment, which depends on the nature of the impacts identified.

On the other hand, one perceived disadvantage might be the time required for public review/comment and a possible public hearing, which might delay a project's progress. However, while the permitting process for the first few projects may be relatively long, it is likely that, as experience, knowledge and awareness of specific projects develops, the EIA process will become routine.

A drawback of the EIA process in its current form with respect to CCS projects is that the focus of the procedure is on identifying and quantifying (local) environmental impacts. The process does not address GHG mitigation accounting needs. On the other hand, the key objective of CCS projects is to reduce a global environmental impact and, given that monitoring is an existing component of the EIA process, the EIA process could be adapted to accommodate GHG accounting.

## 5. Summary / Conclusions

A number of regulatory issues have been discussed above in the context of a specific potential regulatory driver. These drivers are either GHG mitigation, the primary purpose of CCS projects, or HSE concerns, a potential byproduct of such projects. Consideration of the underlying regulatory issues suggests that there are no major hurdles to a regulatory framework for geological $CO_2$ storage that have not been addressed in other types of industrial or engineering projects. Only the timeframe for consideration of these issues is different.

In the context of a regulatory framework for CCS, a flexible, non-prescriptive system appears preferable. In this way, it will be possible to adapt to, and take advantage of, the knowledge that is gained from the collective understanding and experience of the initial CCS projects. In addition, the ability to adapt some existing, widely used framework would be preferable to developing an entirely new regulatory scheme.

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