# State-of-the-Art review of Directives and Regulatory Regimes Related to Operational and Safety Risks

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CGS Europe
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$CO_2$GeoNet
The European Network of Excellence on the Geological Storage of $CO_2$

# CGS Europe Key Report

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# EXECUTIVE SUMMARY

$CO_2$ Capture and Storage (CCS) is recognised as a potentially important corner stone amongst the climate change mitigation technologies in Europe and worldwide. Although individual components of the CCS value chain are proven technologies, as a whole-chain process, CCS is a new technology which was expected to reach fast implementation and at a very large scale in the energy and other industrial sectors. The concern that a rapid implementation could result in a regulatory vacuum, lead the European Commission, the USEPA and other international organisations to proactively work on relevant legislation and directives. Legislation specifically and $CO_2$ geological storage was also implemented at national and regional level in several regions of the world. This legal context forms the focus of this report, but is approached from the practical point in which the storage project and the related operational and safety risks are the starting point.

At time of publication, nearly all EU members have used the EU CCS Directive to implement appropriate legislation that allows the safe and uniform rollout of CCS throughout Europe, especially regarding the geological storage of $CO_2$. Although implementation of the specific regulation is mandatory, member states can autonomously decide whether or not to allow CCS activities on their territory.

Geological storage of $CO_2$ deserves specific attention, and is as such also the focus of this report. This key report is at the same time a highly practical and scientifically sound document, that provides a thorough overview of the legislation and regulation in place in Europe, and compare it with that of other leading CCS countries and regions.

Rather than taking the structure of a legal document as starting point, this report approaches this topic from the following five, very practical angles:

- Storage site operation
- Leakage events
- Monitoring
- Remediation
- Closure and post-closure

These form the main chapters of this report, and care was taken that each of them can be read largely independently from the others, allowing the reader to approach the topic from the angle that is best suited to them.

*$CO_2$ Storage Site Operation Risks and Regulations (Chapter 2)*

This chapter identifies the risks related to the injection phase during $CO_2$ geological storage and summarises the national, European and international legislation of $CO_2$ geological storage and CCS-related legislations. The materials presented provide an overview of the risks arising during the $CO_2$ storage operation phase. Risks are described with regards to their spatial extent and significance: local environmental risks, general operational risk, risks related to $CO_2$ stream composition, pressure and temperature.

The directives and regulations relating to $CO_2$ storage site operation are discussed with a special focus on dedicated CCS legislations at international, European and national levels where available. Besides the CCS specific regulations, the EU Emission Trading Directive, the International Climate Change Legislation and Clean Development Mechanisms and their relations to $CO_2$ storage site operation phase is considered.

Next, the directives and regulations relating to offshore and onshore $CO_2$ storage site operation are presented, followed by brief conclusions.

*$CO_2$ leakage risks and related guidelines (Chapter 3)*

This chapter presents an overview of the international regulations and guidelines related to potential leakage events of $CO_2$ from a geological storage site, an overview of the international regulations and guidelines related to leakage, as well as the effects of $CO_2$ reaching the biosphere.

The chapter starts with a review of the main international acts and agreements that regulate the risk of $CO_2$ leakage, the London Convention and Protocol, OSPAR, EU Directives on Geological Storage of $CO_2$ and ETS. These international agreements were elaborated at different times and differ mostly on their focus (e.g. OSPAR focuses only on the effects of $CO_2$ leakage in the marine environment whereas EU Directive on Geological Storage of $CO_2$ refers to $CO_2$ leakage in all environments) and geographical coverage (although they overlap to some extent with regards to this). Still, all regulations require that storage operations are conducted in a safe manner, taking corrective measures in case of leakage. For this reason, they also stipulate the necessity of conducting a thorough risk assessment at each step of a storage project (starting with the pre-operational phase) in order to prevent and mitigate the identified hazards.

In this context, another important part of the chapter refers to guidelines for risk assessment, especially the ones developed under OSPAR (FRAM) and EU CCS Directive (Guidance Document 1). These guidelines comprise several stages for risk assessment, covering the entire cycle of a $CO_2$ storage project, starting from site characterisation to risk management (including monitoring and corrective measures).

A first step in the risk assessment for a $CO_2$ geological storage site is to identify all of the potential risks related to the site, especially the potential leakage pathways, presented within this chapter, such as permeable caprock, faults and fractures, wells and other anthropogenic pathways (e.g. hydraulic fracturing of reservoir possibly connected to a $CO_2$ storage site or extension of fractures to the $CO_2$ storage complex).

The final part of the chapter presents the effects of a potential $CO_2$ leakage on the environment and on human safety and health through a few studies made on this topic using natural analogues (e.g. Laacher See, Germany; Panarea Island, Italy) and some incidents and regulations related to human and animal exposure to increased levels of $CO_2$. Although the exact effects of a $CO_2$ leakage are not yet known (as the composition of $CO_2$ stream and the re-actions of co-injected elements play an important role in this issue and there is still a research need for controlled $CO_2$ leakage), it is commonly accepted that $CO_2$ leakage can cause acidification of sea or groundwater, mobilisation of toxic elements (due to pH change in soils), adverse effects on plants, animals and humans.

*Directives and regulations related to storage site monitoring (Chapter 4)*

This chapter provides an overview how monitoring is addressed in legislation and directives, how guidelines and protocols have been developed to interpret the legislation and how some of the early integrated industrial scale CCS projects have incorporated monitoring plans in their permit applications.

Legislative regimes of EU, US, Canada and Australia were reviewed. The focus was on EU legislation and its CCS Directive and ETS Directive. The associated Guidance Documents and ETS-MRG guidelines provide more practical information on how to translate legislative monitoring requirements to a practical implementation and what role should monitoring play in case that leakage occurs. The high level content concerning monitoring of various international documents such as OSPAR, the London Convention, the IEA-MRF, CO2QUALSTORE as well as the IPCC Special Report and its Guidelines have been

incorporated in many regulatory regimes, including the EU CCS Directive. The EU and Australia can be considered the leading players in establishing CCS related regulation frameworks, closely followed by the US and Canada.

A comparison of regulatory documents from different jurisdictions showed, that the objectives for monitoring are similar in terms of tracking the injected fluid in the subsurface and to monitor key risks related to HSE. Further common principles are that monitoring plans should be risk and objectives based, site specific and non-prescriptive in terms of technologies applied. While the EU regulation is entirely focused on emissions reduction objectives, the USA regulation seems more focused on enhanced oil production (EOR) and so called CCUS (carbon capture, use and storage). Moreover, EU legislation requires permanency of stored $CO_2$, while the US (and Canadian) legislation seem to accentuate stronger the utilisation of injected $CO_2$. In all cases long-term liability provisions need further revision and consolidation. Regular reporting of the results of monitoring to a competent authority is always requested. It will be crucial that the performance quality and the relevancy of specific operational procedures and/or corrective measures taken are inspected by a competent authority. However, minimum competency requirements for the verifier are not defined in the CCS Directive. It may be worth considering the introduction of an accreditation procedure for verifiers under the CCS Directive at different levels (national, international).

Some examples of integrated industrial scale projects implementing monitoring plans in their permit applications have been evaluated in this document. Information has been taken from published FEED studies as well as from storage permit applications. As one might expect, major differences exist between onshore storage (e.g. the Quest project in Canada) and offshore storage (e.g. the ROAD project in the Netherlands).Though differences can clearly be identified, all examples follow a similar risk-based approach for defining the monitoring plan. In all cases, wells were identified as potential hazards, either in terms of potential $CO_2$ leakage along the wellbore, or induced brine migration by the elevated pressures in the reservoir. Monitoring techniques selected depend on the geological setting and on the type of wells. Nevertheless, the monitoring plans do show many similarities.

In Guidance Document 2, data retention and ownership of the information from monitoring reports are considered. In Europe at present, it is up to the Member States to choose which approach to follow and to establish appropriate regulations concerning the access to and the rights to use the information. It is important to balance between proprietary rights and the transparency for public. Eminent participants (scientists, stakeholders, regulators) are of the opinion that openness and transparency should be a top priority. At least two reasons exist for such conviction: firstly the ability to develop new knowledge through circulation of information and secondly to build public confidence in CCS technology. However, how, who and to what extent to communicate the monitoring results (and other information on CCS in general) remains ambiguous.

*Directives and regulations related to storage site remediation (Chapter 5)*

Remediation measures are applied in case a significant irregularity in the behaviour of a storage site or a leakage of $CO_2$ from a storage site occurs. They can be divided into three categories, depending on the nature of the event. The first category applies to wells and includes well intervention techniques that can mostly be based on proven practice from the oil and gas industry. The second group refers to leakage through geological pathways like caprock failures or faults. In this case the remediation measures usually involve injection and pressure management modifications and/or use of low-permeability “healing” materials. The third case is leakage into overlying aquifers (including potable groundwater resources and near-surface structures) where techniques common in hydrogeology and pollution control are considered.

A special group of newly developed techniques, directed specially at remediation of $CO_2$ storage sites, include application of special materials (special cements, self-healing substances, etc.) or specifically

tailored aquifer management techniques. These techniques are the subject of intensive on-going research and development, and further improvements in this field are expected in the near future.

Remediation measures are an integral part of regulatory regimes for CCS in all relevant countries and regions where CCS activities are on-going or planned. The CO2QUALSTORE guideline (Aarnes *et al*., 2010) considers contingency and remediation planning an essential part of the risk and uncertainty management, providing a systematic approach to the issue. The European regulatory framework is based on the EU CCS Directive (2009) and Guidance Documents 1 and 2 (2011). The key instrument is the risk-based and site-specific corrective measures plan which has to be prepared by the storage site operator as part of storage permit application.

The international comparison shows that most of the regimes are based on similar foundations, closely linking risk assessment, monitoring and remediation measures into one mutually interconnected package. The European and U.S. legislations appear to be the most detailed and most elaborated.

*Directives and regulations related to storage site closure and post closure (Chapter 6)*

This chapter provides an overview on the methods and the regulatory requirements for $CO_2$ injection sites over the period of closure and post closure. It is structured chronologically, starting with the process of abandoning the injection wells and concludes with an overview of how the liability for the project site can be transferred to the relevant authorities.

The first part briefly discusses the different regulations concerning $CO_2$ site closure, which are still under development (especially the national directives). The chapter also provides information on already existing requirements for well abandonment in the hydrocarbon industry, using international conventions as well as accessible regulatory data from countries engaged in oil and gas production. The regulations for decommissioning of oil and gas production operations have already served as a general basis for developing guidelines concerning the handling of $CO_2$ sites because of the similarity of the subject.

Among the activities conducted during site abandonment, well abandonment is considered the most important process, as it should prevent all physical hazard induced by the well, prevent any migration of contaminants and ensure that no communication between originally separated hydrological systems is occurring. Therefore, the chapter also provides a brief overview on the potentially required technical details (plug placement) as well as overall objectives of proper well abandonment (preserve hydrogeological systems).

Following well abandonment, the post-closure phase is described, starting with a brief discussion on how to prove the safety of stored $CO_2$. After summarising the iterative process of characterisation of the reservoir, the general requirements for long-term storage safety, certain modelling techniques, risk management and suitable monitoring options are discussed. As all monitoring plans must be chosen according to the particular risks of the project, a variety of monitoring options also are presented.

The last step in the post-closure phase is represented by the transfer of liability. Exemplary regulations, like the EU Guidance Documents are discussed briefly.

Generally the phase of closure and post-closure is the part of the CCS life-cycle that has been practised the least, which leaves room for developments and discussion, especially concerning the final step of transferring the responsibility of the site.

*Conclusions and recommendations (Chapter 7)*

Based on this regulatory overview, several issues regarding $CO_2$ storage risk legislation could be identified. A number of these are already addressed by the instances involved. Recommendations are given here with the objective to facilitate permitting and administration, but also to create more transparency on liabilities and to facilitate the commercial introduction of CCS.

- Because regulations on storage are elaborate and newly introduced, overlaps with other national and international legislations exist that interfere and sometimes contradict them. Overlaps generally occur between specific and non-specific CCS legislation such as those for water or waste management. These overlaps need to be properly addressed, and care must be taken to ensure transparent and stable regulations for the (storage) operators. Most overlapping legislations are currently undergoing revision.
- Leakage is not uniformly defined in different regulations. This should pose no direct problems, but again different and contradicting regulations might apply to the same project. Moreover, diffuse leakage may be present but not detected with the monitoring equipment used in the monitoring time interval. Such situations are currently insufficiently addressed.
- The utilisation of $CO_2$ (CCUS, EOR etc.) could provide the business case for jumpstarting wide-scale deployment of CCS technology and appropriate and transparent regulations should be available. Complementary regulations between oil and gas production and CCS activity is therefore needed. In general, developing a CCS legislation can benefit from experience in the oil and gas industry and legislation.
- For all legislations the long-term liability provisions need further revision and consolidation. There are few prescriptions of the requirements during the closure and post-closure stages, as there are no projects within this timeframe yet. Better definitions of necessary tasks would lead to better understanding of expectations on the operator's part. Especially under the USEPA regulations there is no description of transfer of liability for long-term stewardship after site closure, while this aspect receives significant attention in the EU CCS directive.
- Specifically for the EU, the ETS Directive contains minimum competency requirements for the verifier of the monitoring and risk assessment reports. In the CCS Directive however, there is no mention of such requirements. It may be worth considering the introduction of standards for verification bodies regarding their knowledge, experiences, independency etc. This may result in the introduction of an accreditation procedure for verifiers under the CCS Directive at different levels (national, international).
- Uncertainties are a specific issue in geology. It should be clear how these uncertainties should be handled and the the confidence levels are required in modelling as well as the accuracy levels required in the monitoring used to verify modelling results. Uncertainty management and confidence/accuracy requirements on all storage aspects should be included and set realistically, for a given storage site setting.
- Currently, there is no obligation to keep a public register of storage sites under the US EPA regulations, nor in the IEA MFR guidelines. Although the level of disclosure that is necessary is still under discussion, such a register could increase public confidence.

This review has revealed that for countries that have a dedicated CCS regulation, although some issues still exist, most risks are covered. For countries looking to implement regulations, guidelines exist and installed legislation can serve as an example. Because CCS is a relatively new technology, experience will also guide new regulations. As investment and environmental risks are large, regulators need to be sure that risks are properly managed and operators need to be confident that liabilities are covered.

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