An overview of international practices for authorization and monitoring CO_2 storage facilities

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***Abstract*— *The present work intends to approach the literature review related to the regulatory structure and legal requirements to obtain authorization for commissioning and operation of CO2 storage installation, as well as an approach to methodologies for monitoring operational aspects and technologies used for this purpose. The importance of monitoring as a fundamental part to guarantee the integrity and safety of the facilities will be scored together with the risk management practice using a methodology called bowtie. As a result, flaws in the monitoring process of the CO2 storage facilities can be verified and how the parties involved in the process can be held responsible*.

***Keywords*—Carbon, Capture and Storage; Regulatory Framework; Integrity and Security facilities; Failures and Liability of the Parties.**

I. INTRODUCTION

In the contemporary context, the issue of climate change mitigation is the subject of international consideration. In the meantime, companies and governments are looking for alternatives to deal with climate change, caused mainly by global warming, made possible by the intensification of greenhouse gas emissions. Among projects capable of mitigating the emission of these gases, there is a technology called Carbon Capture, and Storage (CCS). (NUNES; COSTA, 2019)

However, to perform such an activity it is necessary to comply with a series of requirements and authorizations, being a common practice in several countries studied by the International Energy Agency (IEA) and required in several ways, from a single authorization or license to a combination of multiple authorizations and/or licenses, being able to cover both the operation and the decommissioning (IEA, 2010).

In general, a significant amount of information is required before a grant is provided. This information includes details of how the project will be operated, including results modeling and a monitoring plan, and how the project will be completed, including decommissioning and rehabilitation plans. Since this information is provided prior to the start of the injection, all revised documents include mechanisms to update these plans in the light of the data generated throughout the project (IEA, 2010).

All of these rules take place through laws, regulations, and other rules issued by the government and can be defined as a form of State intervention to discipline the functioning of markets, thus limiting the degrees of freedom of economic agents in decision-making (RATHMANN, 2017).

The scope of a regulatory CO2 storage framework varies significantly depending on the environment in each country (COSTA et al., 2018). There may be limitations in scope that include only onshore storage regulations and not offshore, geological, or related to the volume of CO2 injected. Several revised IEA documents also specify relevant prohibitions for the storage of CO2, for example, restrictions on storage in the water column (ocean storage). (IEA 2010)

Following practices and recommendations are important, including studies that find a positive correlation between operational performance and reputation, improving the company's assessment of interest groups and a resource to be used both for higher superior economic performance and for times of crisis, such as environmental accidents. (VARELA, 2014)

In addition, the company must account for and take into account in its decisions all members of this interest group such as shareholders and investors, customers, governments, and suppliers. And, traditional notions of corporate social responsibility imply that companies must be accountable to the communities in which they are located. (VARELA, 2014).

Thus, the purpose of this article is to review international practices and recommendations with a focus on themes related to authorization and monitoring of CO2 storage facilities. In this line, topic 2 presents a summary of the regulatory structure and steps for obtaining authorizations for commissioning and operation of the installation. Item 3, we show a view of the operational parameters associated with the monitoring process of the facilities necessary to guarantee their integrity and safety, a topic that will be explored in detail in item 4. Item 5 addresses the failures that may occur in the process monitoring and respective accountability by the parties. Finally, we bring final remarks.

II. REGULATORY STRUCTURE AND AUTHORIZATION FOR COMMISSIONING AND OPERATION OF THE INSTALLATION

The International Energy Agency produced in its Regulatory Framework Model a series of processes and standards for obtaining authorizations throughout the project.

According to the IEA (2010), CCS regulatory approaches must require operators who wish to develop and operate storage facilities to apply to the competent regulatory body for specific storage authorization before proceeding with the development of the project. An authorization process allows the disclosure of technical details of the proposed site and the planned mode of operation, as well as the opportunity for regulators to evaluate the technical details of the site and to measure the operator's training, as well as to allow stakeholder consultation on the project, including the general public (IEA, 2010).

The IEA's Regulatory Framework Model (2010) also addresses details about the storage authorization application that will generally require the disclosure of the following information:

- Details of the legal entity proposing the development and operation;

- Evidence of the technical competence of the entity that will develop and operate on the site;

- CO2 source (s) to be received for injection, including composition, delivery rate, time and expected date of cessation of the CO2 offer;

- Planned injection site (s), storage site (s), injection mass (per unit time and total) and so on;

- Location and geographic extent of the storage location, including details of the storage complex;

- Results of the site characterization process, including all the information collected and research work carried out (data sets, maps, etc.) and the results of interpretation and analysis;

- Results of reservoir modeling studies and sensitivity analysis;

- Results of the risk assessments carried out; Operating modes proposed for the storage complex (injection sites, pressures, injection rates, etc.);

- Contingency plans in the event of any significant leak, unintended migration or irregularity in a storage location;

- Preliminary results of the baseline survey for the site; Monitoring plan proposal;

- Consideration of other storage activities in connected formations and pressure interactions as a result of new developments;

- Details of other activities in the area, including the subsurface and adjacent surroundings and in the area covering the planned storage location;

The regulatory body must assess a requirement on technical and legal merits and determine whether authorization will be granted (IEA, 2010). The regulatory body must then deal with any questions raised and determine whether to issue an authorization (IEA, 2010). If the regulatory body does not feel sufficiently informed about the short, medium and long term security of the location or the economic viability of the operations, the applicant should be allowed to provide additional information and analysis or the application for authorization should be denied (IEA, 2010).

It may also be useful to establish a minimum volume of CO2 storage in a structure to simplify the approval process for research and development scale projects (IEA, 2010). The European Union's CCS Directive, for example, set its minimum regulatory threshold at 100,000 tonnes of CO2, which effectively exempts small-scale projects from the approval or authorization requirements that apply to larger projects (IEA, 2010). However, scale research and development projects may still require authorization processes for some activities in the European Union (IEA, 2010).

From a legal perspective, regulatory frameworks for CO2 storage must ensure that any significant leak, unintended migration or other irregularity in the storage

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site operations is corrected so that any damage is remedied. Regulatory CO2 structures should stipulate who will be financially responsible for remedial and remedial measures and who will carry out these measures (IEA, 2010).

Meanwhile, from the group of countries that have specific legislation on CCS activities, issues related to operationality, such as Monitoring, Reporting and Verification (MRV) routines have definitions of methodology for obtaining the licensing of CO2 capture and storage operations, as well as the way the owners of the places and operators should manage such operations, also specifying periodicity and minimum technical characteristics for issuing reports accompanying the activities. (IEA, 2010).

The Australian law called the Greenhouse Gas Geological Sequestration Act (2008) states that before starting the injection of CO2 or other greenhouse gases, the holder of an injection, monitoring and license must submit to the Minister a "monitoring and injection plan", including a description of the proposed monitoring techniques, monitoring and verification plan detailing how the behavior of any stored greenhouse gas will be monitored and an estimate of the cost of monitoring and verification activities (IEA, 2010).

The Canadian carbon sequestration tenure regulation (Canadian Carbon Sequestration Tenure Regulation) complements the licensing issue (IEA, 2010). This regulation determines the need for all MRV plans to present an analysis of the likelihood that operations will interfere with mineral recovery, in addition to linking the renewal of the contract / lease to the triennial renewal of MRV (IEA, 2010). This law also establishes obligations to obtain contracts such as the payment of the application fee prescribed in the Regulation, payment of the rent applicable for the first year of the contract, presentation of evidence that the area covered by the application is suitable for CO2 sequestration, shipping a monitoring, measurement and verification plan for approval and submission of a decommissioning plan (IEA, 2010).

If the aforementioned standards raise issues relatively marginally, therefore, in a macro context, the North American Code of Federal Regulations, Title 40: Protection of the Environment, Parts 78 (Appeal Procedures) and 98 (Mandatory Reporting Rules) CO2 storage), brings important milestones and definitions as one of the few laws that explain the difference between injector well for CO2 storage and injector well for better hydrocarbon reserve performance and efficiency, as well as determines the obligations and duties of both operators of the owner (IEA, 2010).

US law also establishes well-defined technical and administrative guidelines, such as the need for owners and operators of such CO2 sequestration facilities to follow reporting and monitoring procedures, quality assurance, missing data estimation and maintenance of data. specified records, as well as carbon monitoring, reporting, for example, the amount of CO2 received, injected, produced, emitted by surface leak and emissions from equipment leaks and ventilated emissions from surface equipment (IEA, 2010).

Brazilian legislation, above all environmental, is very comprehensive, covering a wide range of topics (COSTA et al., 2017), although specific CCS activities are not yet covered (COSTA et al., 2018). First, it is necessary to understand that the monitoring phase (including the issuance of reports and eventual inspections) may depend on the type of licensing obtained by the operator. According to art. 225, § 1, IV, it is incumbent upon the Public Power to demand, by the law, a prior impact study on the installation of a work or activity potentially causing significant environmental degradation. Also, art. 23 defines the common competence of the Union, the States, the Federal District and Municipalities to protect the environment and combat pollution in any of its forms (COSTA et al., 2017).

Therefore, to fulfill this role, Law no. 6.938 / 81 (Law of the National Environment Policy) provides in article 10, § 4, the competence of IBAMA for licensing activities and works with significant impact, national or regional, subsequently regulated by Decree no. 99,274 / 90. In the oil and gas industry, the execution of business activities is mostly monitored by the National Agency of Petroleum, Natural Gas and Biofuels (ANP).

It is important to note that the oil and gas sector dominates the techniques of capture, transport and injection of gas in geological reservoirs. In other words, agents working in the oil and gas sector in Brazil have experience in using gas separation technologies in the production of natural gas that would be similar to the technologies used for capturing CO2, for example. Therefore, it makes sense that the regulatory body that should adapt and supervise CCS projects in Brazil has expertise in regulation in the oil and natural gas sector (RATHMANN, 2017).

III. MONITORING OF OPERATIONAL PARAMETERS

The CO2 monitoring practice involves several stakeholders, including the operator, the regulator, and other project stakeholders, including the general public.

Monitoring CCS activities is essential to support several crucial elements of safety and security and will involve a portfolio of monitoring techniques to detect the presence or absence of CO2 in primary formation storage, as well as in the storage complex and on the surface (NUNES; COSTA, 2019)

Monitoring CCS activities is essential to support several crucial elements of safety and security and will involve a portfolio of monitoring techniques to detect the presence or absence of CO2 in the primary formation storage, as well as in the storage complex and on the surface (IEA, 2010). The CO2 monitoring practice involves the operator, the regulator, and other project stakeholders, including the general public (IEA, 2010).

To this end, a Monitoring Plan must be built in order to formalize and register with the regulatory bodies and licenses a standardization to be followed in this phase. The standardization and disclosure of the Monitoring Plan gives robustness to the project, demonstrates the organization of the company, and shows investors and agencies confidence in the company's management structure and its commitment in the area of Quality, Safety, Environment, and Health (NUNES; COSTA, 2019).

The data obtained in the technical feasibility stage will allow a characterization and will provide the selection of suitable storage locations, with appropriate capacity, injectivity, and entrapment, as well as to design safe operational parameters, such as maximum injection rates (KETZER et al., 2016). Strict characterization is also necessary for a thorough risk assessment process, in order to demonstrate that the probability of any leakage event is very low and that any associated impacts can be properly identified, monitored and mitigated (KETZER et al., 2016).

Surface monitoring or close to the surface also needs to be performed before injection to provide reference data and also during/after injection to detect any changes or impacts that may arise in the unlikely event of a leak (KETZER et al., 2016). Several methods can be used for surface and subsurface environmental monitoring, such as chemical and biological analysis, markers, and remote sensing, among others (KETZER et al., 2016).

Therefore, the monitoring, measurement, and verification of CO2 in CCS projects go beyond the limits of the geological reservoir targeted by the injection, or the confinement seal rock, since all areas in which CO2 may migrate must be considered, including soil, water bodies and atmosphere (KETZER et al., 2016).

In addition, as provided by the International Energy Agency, for the CO2 storage to be properly framed according to international standards, it is necessary to definitively trap the gas in an amount greater than 95% of the injected CO2 IEA (2010).

For surface components, standard monitoring techniques (for example, flow measurement and gas analysis) should be used to compile gas flow inventories, including estimates of avoided CO2 emissions and fugitive emissions, as well as for recording injected volume. / mass of CO2 (IEA, 2010). Good operational practice requires continuous monitoring at various locations to establish the mass of CO2 at the point of capture, the mass transferred for transport, the mass received at the injection site, and individual mass flow records in injection wells (IEA, 2010). This is likely to involve a combination of flow, temperature, and pressure measurements throughout the project and should be considered part of a standardized set of techniques (IEA, 2010).

The main objectives of subsurface monitoring include the following:

- Proper operation: to ensure that the agreed and permitted mode of operation is followed (for example, safe tank pressure).

- Early warning: to identify any irregularities in CO2 injection and migration, including any signs of potential leakage or unintentional migration, in order to initiate corrective measures and remediation.

- Validation and calibration of models: Validation of predictions of the CO2 level and destination behavior compared to the observed behavior is an essential part of the best practices for managing CO2 storage sites. Observations can provide new information on the characteristics of the subsurface that affect the behavior and fate of CO2 (for example, compartmentalization of reservoirs, hydrogeology, and geometry), allowing calibration of the model and reformulation of forecasts.

- Emission inventory: to quantify any leakage of CO2 in case it is detected. If the leak is detected, additional monitoring techniques may be needed to support the quantification of emissions.

These components are essential to establish the security of storage operations (IEA, 2010). Consequently, the establishment of monitoring requirements should be a key component of the frameworks for CCS. Site-specific factors, such as depth, surface characteristics, and geology, will determine precise technologies, techniques, and application frequencies to be used in monitoring (IEA, 2010).

Site-specific monitoring requirements (from the IPCC 2006 National Greenhouse Gas Inventory Guidelines) have monitoring technologies that have been developed and

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refined over the past 30 years in the oil and gas industry, groundwater industries, and environmental monitoring. The suitability and effectiveness of these technologies can be strongly influenced by the geology paths and potential emissions at the storage sites, therefore, the choice of monitoring technologies will need to be made site by site (IPCC, 2006).

There are a variety of CCS monitoring technologies designed to monitor the reservoir, overload, the seabed, or the water column. The common objective is to detect, characterize, and quantify any leakage of CO2 from the intended storage location, but the choice of the right technical solution for a given project is not trivial. Seismic studies, for example, offer highly valuable information on the migration and development of the CO2 plume and changes in geophysical properties inside and above the reservoir, but they are expensive and rarely conducted research. Electromagnetic and gravimetric surveys were also used to monitor the stored CO2 plume, offering potentially useful but less detailed information. As shown in Figure 1, several studies highlight the need for a multidisciplinary, site-specific approach to surface CCS monitoring, also covering the overhead, the seabed, and the water column. (WAARUM, 2016)

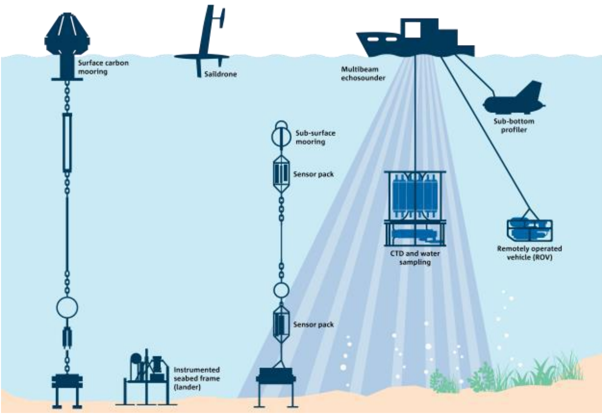

Fig.1 Equipment and technologies for monitoring carbon storage in marine environments

In this sense, the AUV - Autonomous Submarine Vehicle is an example of advances in monitoring technology. Due to the need to cover the storage reservoir area, in addition to taking into account the possible lateral migration of CO2 into the storage complex and the additional lateral movement as the CO2 goes through the overload (which is equivalent to a potentially several hundred square kilometers in area), an unmanned system that can be deployed for long periods is required. The AUV (for example, Fig. 2) can be programmed to follow a predetermined research pattern in high resolution and to house a range of sensors relevant for monitoring CCS leaks (for example, chemical, acoustic, imaging products), having passive detection functionality (for example, chemical sensors and passive hydrophones) that could last for months or active detection (for example, acoustic sonar images on the seabed or subsurface), lasting in the order of days. (BLACKFORD et al., 2015)

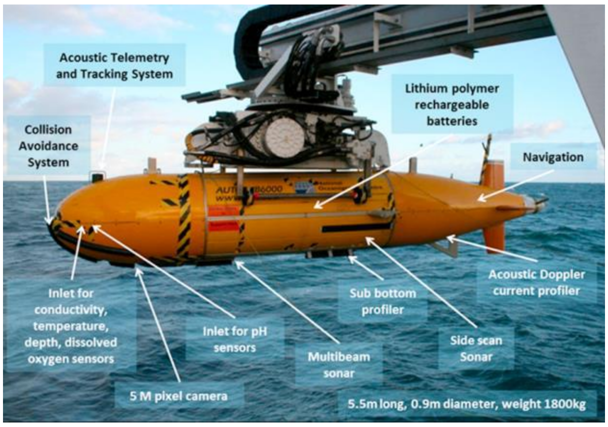

Fig.2 Example of an AUV, with Example of an AUV, with its associated power, navigation and sensor systems its associated power, navigation and sensor systems

Technological limitations, costs, frequency (continuous, annual, etc.), need for mapping and description of the storage location are factors that influence both the choice of technology to be used and the elaboration of the monitoring plan. (IPCC, 2006).

Another relevant aspect for study and monitoring is the natural variation in the conditions of the marine environment, since the biological activity, currents, turbidity, temperature, and water stratification causes the concentration of most substances in the water column to have natural fluctuations. These fluctuations will be the result of several overlapping fluctuations linked to diurnal, lunar, or seasonal changes. This leads to a complex pattern of variation in each of the parameters that makes it difficult to distinguish natural fluctuations from the initial conditions of a leak from CO2 storage. To interpret CO2, pH measurements, or to indicate leaks, it is necessary to have a baseline with natural fluctuations established over time, including daily and seasonal fluctuations. The monitoring of several parameters simultaneously can activate the identification of covariant patterns that characterize natural or leak-related changes and can be used to discriminate between them. (WAARUM, 2016)

Monitoring will also be necessary after the injection is stopped at decommissioning and possibly post-decommissioning. In these periods, the risk of leakage or

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unintentional migration should reduce because the injection, which is the main force in processes and flows triggered by pressure on the subsurface, has ceased (IEA, 2010). In addition, the understanding of the subsurface must also have evolved over time from the initial injection because of the learning and historical process of the site (IEA, 2010). This means that the model's forecasts must converge more and more with the behavior over time. However, monitoring in the decommissioning and post-decommissioning phases may still be necessary, as CO2 will continue to flow and disperse in the subsurface after the injection is stopped (IEA, 2010).

Over time the risk of processes under pressure causing leakage will be decreasing and the expected behavior converging with the observed behavior (IEA, 2010). If there is a high level of confidence that these conditions are being met, it may be possible to completely end any monitoring activity (IEA, 2010). Monitoring may need to start over in the event of events that may have an effect on storage stability (IEA, 2010).

IV. THE KEY ROLE OF MONITORING IN GUARANTEING THE INTEGRITY AND SECURITY OF INSTALLATIONS

Trapping mechanisms have the function of preventing the injected CO2 from migrating back to the surface (ALVES, 2008). According to Alves (2008, p.32): “The pressure resulting from the depth required for its storage causes CO2 to remain in the form of supercritical fluid”, a physical state that provides its “fixation in the intestinal spaces of rocks”, when, then, it will penetrate the existing pores, when the critical depth is reached. Part of this CO2 is by Alves (2008, p. 32), “definitely blocked after the sealing of the injection holes, while another part may move for some years, until it reacts with existing fluids and rocks, mineralizing”.

According to Gaspar (2014, p.37) “with the choice of a suitable location, a monitoring program to detect problems, a regulatory system and the appropriate use of corrective methods to stop or control any leakage of CO2, the environmental risks of the CO2 storage, the health of the local population and safety risks must be comparable to the risks of natural gas storage and oil extraction ”.

For the operator to maintain continuous guarantees that CO2 is being successfully stored, monitoring and reporting activities for CCS projects must be carried out (IEA, 2010). Also, the monitoring of activities should provide sufficient information to calculate the effectiveness of the project in terms of tons of CO2 stored and tons of CO2 avoided. These calculations will provide the basis for awards and adjustments of credits or payments linked to emission reductions obtained by a project (IEA, 2010).

Generally, it is considered that a leak of 1% of CO2 stored in a thousand years would be an acceptable value (KETZER et al., 2016). The flow of CO2 injected into the subsurface can be modeled before injection by simulating CO2 interactions with the reservoir and the rock layer in laboratory tests (KETZER et al., 2016). These experiments simulate subsurface conditions using samples of real rocks and fluids (KETZER et al., 2016). Simulations can also be performed using numerical modeling tools to predict the flow and chemical interactions at the storage location on geological time scales (KETZER et al., 2016). The observed flow of gas injected into the subsurface can be compared with the predicted paths, allowing the calibration of the experimental and numerical models (KETZER et al., 2016).

Bowtie is a method capable of previously identifying degraded barriers to maintain the integrity of the installation and proposing corrective barriers in the event of the occurrence of an unwanted event. The method provides a framework for systematic risk assessment of events with the potential to affect storage performance. The bow tie (Fig. 3) represents the relationship between the five key elements that make it up: (DEAN, 2017)

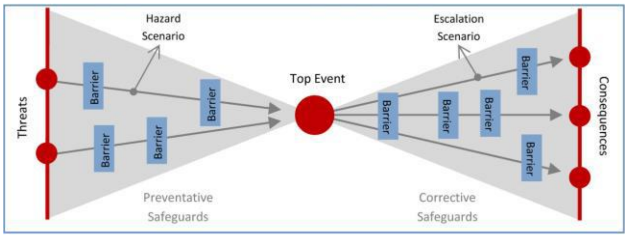

Fig. 5. Schematic diagram of the Bowtie Method

· Main event: this is the unwanted event, placed in the center of the tie. In this case, the main event is the movement of the CO2 cloud outside the storage complex;

· Threats: these conditions can lead to the main event. For example, the presence of a system of permeable faults or fractures, injection-related stresses (pressure/thermal) or poorly connected abandoned wells;

· Consequences: These are the possible adverse results due to the unexpected occurrence of the main event. For example,

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the emission to the marine environment impacting the flora locally;

· Preventive safeguards: decrease the likelihood of a threat leading to the main event. For example, the effects of the injection pressure are likely to be small, as the injection is good and the storage location is under sub-hydrostatic pressure;

· Corrective safeguards: decrease the likelihood of significant consequences due to a top event. For example, the presence of a permeable formation under the seal of the storage complex provides alternative secondary storage;

Therefore, to guarantee the integrity of the CO2 storage facility, a process was developed within a risk management framework that is based on the well-established barrier (safeguard) approach. The objective is to identify the necessary monitoring tasks and their respective technologies to reduce storage risks to a minimum. The following is a step-by-step approach: (DEAN, 2017)

1. Assess site-specific storage risks: Establish definitions for loss of compliance and loss of containment. Identify potential threats and consequences associated with these risk events using the bow tie method.

2. Characterize geological safeguards: identify and assess the integrity of each geological seal inside and above the stored complex.

3. Select engineering designed safeguards: identify and evaluate engineering concept selections that provide safeguards against unexpected loss of well integrity. Assess these initial safeguards: Assess the expected effectiveness of these initial safeguards in relation to the identified compliance and containment threats and their possible consequences.

5. Establish monitoring requirements: Define monitoring tasks to verify the performance of these initial safeguards and, if necessary, trigger timely corrective measures.

6. Select monitoring plans: Select monitoring technologies considering leakage scenarios according to a cost-benefit ratio. The benefits are judged by the effectiveness of each technology in each task. This includes monitoring the baseline, as well as monitoring during the injection and closing phases.

7. Set performance goals: evaluate the expected monitoring capabilities.

8. Identify contingency monitoring: develop alternative monitoring plans to investigate suspected irregularities and establish clear criteria for when and how to implement these continents. The results of contingency monitoring should be included in a corrective action plan.

The regulatory structures of the CCS must enable the regulatory body to verify, through local audits, whether storage projects are being carried out as planned (IEA, 2010). Audits are not exclusive to CCS operations, occurring in most industrial operations, where they involve access to the locations of activities and documents. The auditing power granted by a regulatory CO2 storage structure can extend to access to third party property, that is, to properties beyond the location controlled by the operator (IEA, 2010). Audits are more likely to be needed at the beginning of a project's stage than later in the project's life cycle, as this is the period when less is known about the storage location.

The competent regulatory body can carry out routine and non-routine audits of a storage location, having access to any location that has been or is being used in connection with a project including the property of third parties (IEA, 2010). Audits may include research facilities, visits to injection facilities, assessment of injection activities, assessment of monitoring operations, verification of compliance of the storage location with the plan approved by the competent regulatory agency, and access to all relevant records (IEA, 2010). Audits can begin when an exploration authorization is granted and continue until the transfer of responsibility as well as its frequency varies, increasing if there is a significant leak, migration, or other irregularity in the storage location (IEA, 2010).

The International Energy Agency (2010) warns that audits should include, but not necessarily be limited to, direct site visits to examine the surface of facilities, verification of records regarding the mass of CO2 received, the mass of CO2 injected, activities shutdown, unplanned shutdowns or unintended incidents and results monitoring. The precise timing and frequency of inspections will vary according to particular practice in the region and depending on the site's performance history. However, good practice suggests, according to IEA (2010) combinations of the following:

• At least, annual reports on operational activities and review by the regulatory agency;

• At least routine annual or biannual inspections of operations;

• At least one third-party annual check, with supervision by the regulatory body;

• Non-routine inspections, in order to investigate any reports of leaks, unforeseen migration, significant irregularities, complaints or other situations, as needed;

Inspections must continue during the decommissioning period, although the frequency of inspections can be modified during this phase according to site-specific considerations and the level of confidence in the performance of the storage location achieved by the regulator (IEA, 2010).

It is generally accepted by the industry and regulators currently involved in CCS that the operator, as the entity that oversees the operation of a storage location, is the entity that is best positioned for any liability for damage caused by a storage location during exploration, operation and decommissioning (IEA, 2010).

V. FAILURES IN THE PARTIES MONITORING AND ACCOUNTABILITY PROCESS

An operator will generally be responsible for any damage caused to the environment, human health or other resources and be required to take any corrective or remedial measures associated with the storage location and its costs (IEA, 2010). If the operator has been given CO2 incentives for CCS operations, the operator may also be responsible for compensating for any leakage of CO2 into the atmosphere in the context of the incentive regime (IEA, 2010).

The leak or unintentional migration of CO2 from storage sites can lead to a series of potential impacts (IEA, 2010), which can be categorized as:

- Local Impact: risks associated with health, safety and the environment (HSE) associated with CO2 storage and unintentional leakage or migration. Such risks can be divided into:

- Impact on the surface: potential to cause asphyxiation and ecosystems (effects of CO2 leakage on neighboring populations, worker safety and effects on the biosphere and hydrosphere, such as tree roots, terrestrial animals and the quality of ground and surface water) as well as problems associated with impurities present in the injected material.

- Impact on the subsurface: Contamination through the mobilization of metals or other contaminants that have an increased risk due to the presence of certain impurities. It also has physical effects such as soil surveying, induced seismicity, displacement of underground water resources and damage to hydrocarbon production.

- Global Impact: when CO2 is released into the atmosphere due to the leakage of stored CO2, it compromises the effectiveness of a CCS project as a technology to mitigate climate change (IEA, 2010).

Public opinion is always important and that is why governments and companies seek to minimize the negative impacts of their operations. About CCS monitoring, unwanted advertising can result, for example, from observations of CO2 bubbles emanating from the seabed near a storage location or a change in the local marine environment. In such cases, it is beneficial for the operator to minimize damage to reputation by documenting that it has a robust and efficient monitoring process that can locate, quantify and characterize any leakage at an early stage. (WAARUM, 2016)

The absence or failure in monitoring can lead to the occurrence of major socio-environmental disasters, where an immediate drop in the value of the shares of the responsible companies is common. In this case, many investors are expected to sell their shares because of the associated risk and because it may take years for the causes of the accident to be known. (VARELA, 2014)

There must be a framework that addresses the issue of corrective measures, remediation measures and responsibility for the implementation of these measures to operators (IEA, 2010). Given the very specific nature of the corrective and remedial measures that may be necessary, the revised documents tend to confer discretion on the regulatory body to determine when corrective and remedial measures will be necessary and what they will entail (IEA, 2010).

In the event of a significant leak, unintentional migration or other irregularity, the operator must immediately notify the competent regulatory agency (IEA, 2010). The operator must take any corrective measures, as determined by the regulatory body, to protect the environment, human health, other resources and assets of third parties, including actions set out in the operator's corrective action plan, - approved by the regulatory body - as well as any remediation measures (IEA, 2010).

The regulatory body is responsible for taking corrective or repair measures at any time, including at the expense of the operator, while the responsibility for the storage location lies with the operator (IEA, 2010). The operator must update the corrective measures plan to reflect lessons learned and take corrective measures (IEA, 2010).

Corrective measures are needed to protect human health and the environment, and to maintain the effectiveness of a CCS project as a method of reducing CO2 emissions (IEA, 2010). Remediation is necessary to resolve any damage associated with significant leakage, unintended migration or other irregularity in the operation of a storage location. The best practice examples for such measures are those adopted in the oil field as well clogging techniques using heavy mud, as applied in the case of blowouts, standard well repair techniques in the event of well failure and interception of leaking fluids a nearby well to intercept the leak (IEA, 2010). Other measures may involve the partial removal of CO2 from storage to reduce the pressure reservoir and remediation of groundwater in case of contamination (IEA, 2010).

Appropriate mechanisms should be designed to provide clarity about the entity to be responsible for global or local issues. The effects are vital when designing CCS regulatory structures (IEA, 2010).

Liability for any localized effects arising from CO2 releases or storage can be legal / administrative (for example, violation of authorization conditions), criminal (for negligence, wrongful death and environmental crimes) or civil law itself (for example, through damages to third parties), in addition to the civil environmental (IEA, 2010).

The precise nature of the liability will depend on the laws in force in the local jurisdiction, the actions that give rise to any leakage event or unintentional migration (due to conditions of authorization by the operator, negligence) and the nature of any impacts of such events (or that is, level of damage) (IEA, 2010). In practice, it may depend on regulatory / administrative law, criminal and / or civil lawsuits (IEA, 2010).

When developing CCS regulatory structures, there are two main issues to consider (IEA, 2010). First, regulations must ensure that authorization processes establish powers for the competent regulatory body to investigate and file charges in case of violation of authorization conditions (IEA, 2010). Second, any existing laws relating to industrial, civil and environmental accidents, environmental protection and environmental liability must be carefully reviewed (IEA, 2010).

In Brazil, Law no. 9.605 / 98 (Environmental Crimes Law) and Decree No. 3.179 / 99, which regulates it, define the responsibility of the legal entity - administrative, civil and criminal - and also allows the individual responsible for the offense to be prosecuted. Inspection actions are performed by ANP - National Agency of Petroleum, Natural Gas and Biofuels in the form of audits, through samples and analysis of data and evidence, which aim to verify the operator's compliance with the requirements of the technical documentation regulated by the Resolution ANP 37/2015, which provides for the granting of a deadline for the treatment of non-conformities and the eventual elaboration of an infraction notice.

VI. CONCLUSION

According to the most accepted international concepts for project definition, the activity of monitoring CO2 storage facilities can be considered as such, since it has a well defined and outlined scope, it brings requirements related to quality, schedule and budget well developed and detailed and, mainly, it has the predictability and dimensioning of resources to be used during the execution of activities and a robust risk analysis to bring security to the operation.

In this sense, the fact that the monitoring activity is developed as a project, it is possible to calculate and anticipate almost all the risks involved. Monitoring makes it possible to assess threats and anticipate measures to mitigate their effects even before the stage of granting authorizations for commissioning and operating storage facilities. In this way, it is clear and established all the risks involved in the project and how the monitoring will be carried out throughout the project.

For this purpose, the execution of the monitoring must follow the one approved by competent bodies and improved over time, managing and mitigating new risks that may be presented during the operation of the installation. Also, the monitoring plan must be strictly followed and constantly reviewed.

In this way, following the monitoring plan, periodically issuing the reports and performing critical analyzes of the process as a whole, it is possible to anticipate problems and facilitate decision making in an agile and efficient way, enabling preventive correction and preventing accidents such as large spills CO2 quantities.

In this sense, in the event of a leak, a robust monitoring plan will bring tools capable of reducing the damage caused, such as bowtie, which provides all the necessary barriers to prevent the occurrence of events and, when they do occur, the barriers and actions capable of mitigating will be established. its consequences.

In this context, monitoring becomes essential to reduce the operator's exposure to the competent bodies and even to reduce costs in an eventual accident. The fact of obtaining tools that prevent accidents shows a degree of maturity and differentiated management.

The fact is, it is necessary not only to be whole, but also to appear to be whole. The reporting of failures through reports, the communication of any leakage events, regardless of the size and a routine of disclosing the results of the audits, increase the operator's reliability about the agents involved, including shareholders and the society itself.

Therefore, following the practices and recommendations related to monitoring and constituting such activity as fundamental within the project is essential for the operation of CO2 storage facilities safely and cost-effectively, serving the greatest purpose, the mitigation of climate change.

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