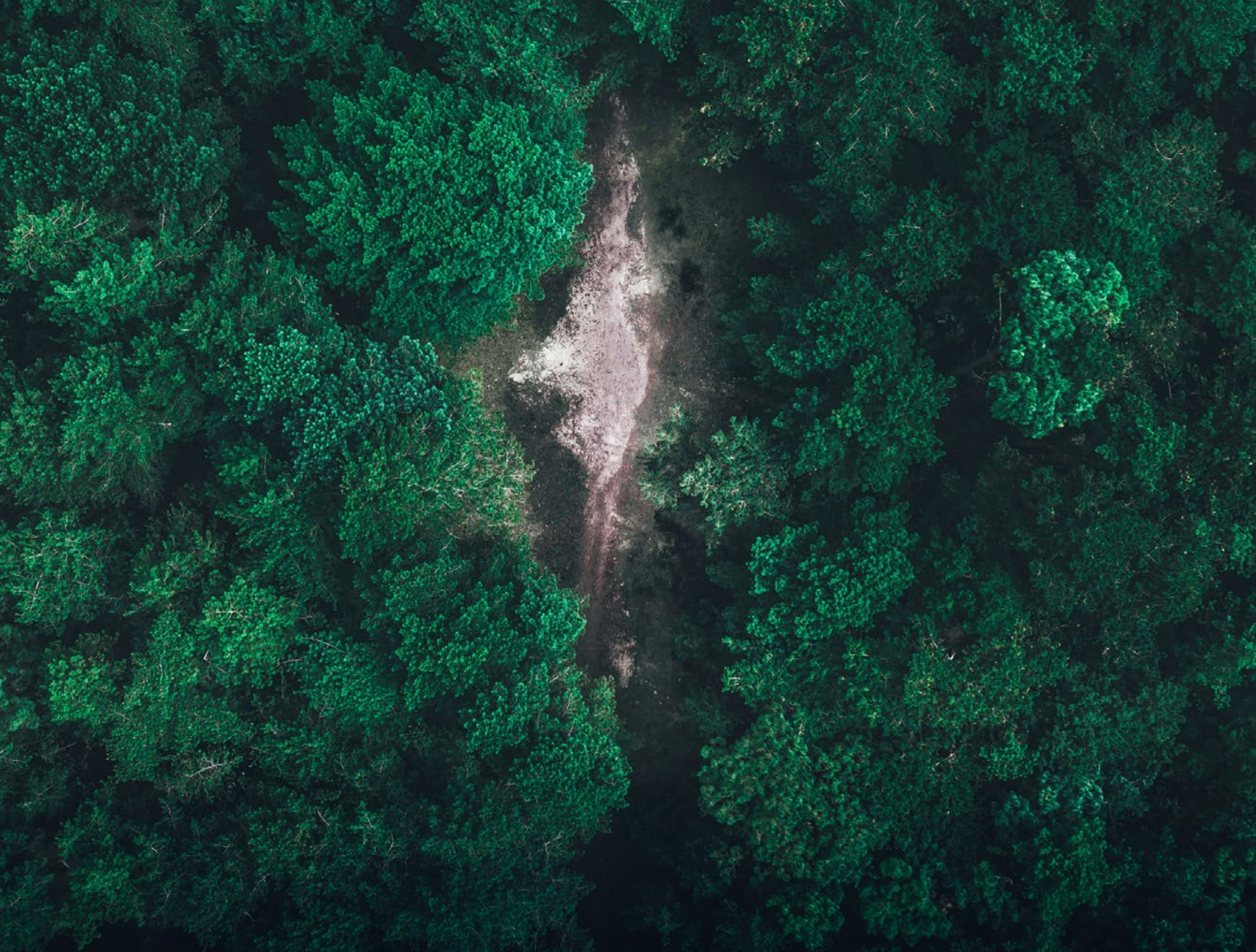

THOUGHT LEADERSHIP

POLICY RECOMMENDATIONS FOR ACHIEVING CO_2 GEOLOGICAL STORAGE WITH ENVIRONMENTAL INTEGRITY IN CHINA

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EXECUTIVE SUMMARY

Carbon Capture, Utilisation, and Storage (CCUS) is poised to become a major pillar of China's strategy to achieve carbon neutrality before 2060. Since the nation's climate pledge in 2020, CCUS has garnered significant attention from policymakers and industry leaders. National initiatives such as the "2023 Implementation Plan for Green and Low-Carbon Technology Demonstration" and the "2024 Action Plan to Reduce Coal Emissions" have formally integrated CCUS, leading to increased governmental support. Noteworthy developments include the operation of China's first integrated megatonne-scale CCUS project in 2022, the commissioning of the world's largest cement-sector oxyfuel CCUS facility in 2024, and a growing portfolio of large-scale capture and storage projects across both power and industrial sectors.

Despite this momentum, China's geological CO_2 storage efforts remain in the early stages, with a comprehensive regulatory framework still under development. Key components such as site selection, risk assessment, long-term liability, and environmental monitoring require more detailed guidelines. Ensuring environmental integrity is paramount; a robust regulatory framework must guarantee the safe and permanent containment of CO_2 while safeguarding groundwater, ecosystems, and public health. Well-designed regulations not only mitigate risks like leakage or pressure interference but also bolster public confidence in CCUS as a viable climate solution.

This report identifies existing regulatory gaps and offers actionable recommendations to assist China in establishing an environmentally responsible and internationally aligned framework for geological storage.

Drawing from over two decades of global experience, the report examines best practices and regulatory models developed by entities such as the International Organization for Standardization (ISO), the US Environmental Protection Agency (EPA) with its Class VI Rule, the European Union's CCS Directive, the World Resources Institute (WRI), the International Energy Agency (IEA), and the Environmental Defense Fund (EDF). These frameworks consistently emphasise leak prevention, groundwater protection, and seismic risk mitigation. They also provide practical examples of how regulations are structured, implemented, and supported by broader environmental laws and financial accountability mechanisms, offering valuable insights for China's regulatory design.

The report distills key technical and environmental requirements from international models across the full project lifecycle, including CO_2 stream characterisation, site selection and modelling, well construction, monitoring, closure, emergency response, and financial assurance.

While China currently lacks a unified legal framework for geological storage, its existing environmental laws and decades of experience in environmental protection provide a solid foundation. These include the Environmental Protection Law (1989, amended 2014), the Water Pollution Prevention and Control Law (1984, amended 2008 and 2017), the Environmental Impact Assessment Law (2002, amended 2018), and the Mineral Resources Law (1986, amended 2020). These laws mandate Environmental Impact Assessments (EIAs), public consultation, and risk management.

Concurrently, China is drafting national standards grounded in ISO models, such as the Geological Storage Standard (based on ISO 27914:2017) and the EOR Storage Standard (based on ISO 27916:2019). Once finalised, these standards aim to guide project developers on critical aspects like site selection, injection operations, risk management, and monitoring, aligning domestic practices with international best practices.

To facilitate the commercial deployment of geological CO_2 storage, this report recommends that China establish dedicated regulations or integrate storage-specific provisions into existing environmental legislation. A clear and robust regulatory framework would define the roles and responsibilities of relevant government agencies, streamline oversight, and provide legal certainty for investors and project developers. It should include detailed provisions on site permitting, characterisation, monitoring, closure procedures, and long-term liability management.

Meanwhile, aligning China's domestic regulations with international standards would not only strengthen environmental safeguards but also foster international collaboration, investment, and knowledge exchange. Key technical considerations are summarised in the table.

PROJECT STAGE	KEY TECHNICAL CONSIDERATION	REGULATORY APPROACH
Pre-injection	• Carbon dioxide stream characterisation • Site selection and characterisation • Storage unit requirements or reservoir suitability • Leakage pathway assessment	• Permitting & Approval
Operations	• Well construction and completion • Well operation • Modelling & Monitoring of Plume	• Monitoring, inspections, verification • Reporting • Enforcement (Fines, permit suspension)
Site closure & post-closure	• Post-Injection site care • Injection well plugging	• Monitoring, inspections, verification • Reporting • Certification • Enforcement (Fines, permit suspension)
Cross-cutting	• Area of review • Demonstration/verification of secure storage • Testing and monitoring plans • Emergency response Plans • Financial assurance • Public outreach	

More specifically, the report calls for:

- Developing enforceable standards for CO_2 stream composition that align with international norms.
- Accelerating the adoption of ISO standards to the national context, creating specific guidelines for site selection. This should encompass fault mapping, area of review (AoR) modelling, and the identification of potential leakage pathways to ensure comprehensive site characterisation.
- Developing robust monitoring strategies that cover the entire lifecycle of CO_2 storage projects.
- Establishing clear protocols for risk assessment and incident response. This framework should include measures for managing seismic risks, conducting routine training exercises, and setting requirements for post-injection monitoring to maintain environmental safety and track containment.

Together, these recommendations aim to support China to build a robust and environmentally sound regulatory environment that enables the safe and scalable deployment of CO_2 geological storage.

1.0 INTRODUCTION

1.1 Overview of China's progress on CCUS[1]

Carbon Capture, Utilisation and Storage (CCUS) is a critical technology for China as it seeks to decarbonise its economy and achieve carbon neutrality before 2060. CCUS involves capturing carbon dioxide (CO_2) emissions from industrial processes, power plants or the air, transporting it, and then storing it safely in deep geological formations. Since the country committed to achieving carbon emissions peaking and neutrality in September 2020, CCUS has been recognised by both industry and academia as a crucial solution for decarbonisation in the power and industry sectors (Zhang et al., 2023).

This recognition is evident in China's policy documents and the tangible project developments. China has taken steps to test policy instruments for the wider deployment of CCUS. Notably, the National Development and Reform Commission (NDRC), in collaboration with 10 other ministries, unveiled "the Implementation Plan for Green and Low-Carbon Technology Demonstration" in August 2023.[2] This plan is China's first policy initiative supporting selected projects with the central government's budget, including CCUS alongside other green technologies like energy storage, green hydrogen, and advanced power grids. In April 2024, the NDRC announced its first batch of selected projects, with six out of 47 related to CCUS, including Huaneng's coal-fired power plant CCUS project and Baotou Steel's Inner Mongolia-based project.[3]

China National Petroleum Corporation's (CNPC) Daqing Oilfield successfully conducted a carbonated water injection test in September 1965, marking the beginning of the CCUS industry in China. However, the real momentum didn't begin until after China announced its carbon neutrality commitment in September 2020. In August 2022, SINOPEC launched China's first integrated megatonne-scale CCUS project in Shandong province. Since then, significant milestones have been achieved in the country's CCUS efforts. These include the launch of China's first offshore CO_2 storage project, its first commercial-scale CO_2 transport pipeline, and a 500 ktpa coal-fired power plant CCUS project in 2023. In January 2024, China United Cement began commissioning the world's largest oxyfuel combustion CCUS project with a scale of 200 ktpa in Qingzhou, Shandong, which is also the largest in China's cement sector. In May 2024, Xinjiang Oilfield, a subsidiary of CNPC, started construction on the first phase of a 2 Mtpa coal-fired power plant CCUS project. This large-scale project, part of a broader initiative including solar power and ultra-supercritical coal units, will capture 1 Mtpa of CO_2 for enhanced oil recovery. In September 2025, Huaneng's 1.5 Mtpa coal-fired power plant CCUS project in Gansu commenced full operation, which is now the largest coal-fired power CCUS facility globally.

Despite all this significant progress, China has made limited advancements in dedicated CO_2 geological storage, as well as the development of comprehensive regulations for storage activities. Geological storage remains in the early stages of development. Moreover, a systematic regulatory framework for overseeing CO_2 storage activities is still lacking, with critical aspects — such as site selection, well integrity, leak prevention, long-term monitoring, risk management, and liability frameworks — yet to be fully addressed. This regulatory gap presents a significant challenge for the commercial-scale deployment of CCUS in China.

1.2 Environmental integrity is central to CO_2 geological storage regulations.

Environmental integrity is paramount in the regulation of CO_2 geological storage activities, as it ensures the safe and long-term containment of captured CO_2 without negatively impacting the environment, public health, and groundwater resources. The successful implementation of CCUS technologies hinges on the ability to securely store CO_2 in deep geological formations, while preventing leakage or migration to unintended areas. If CO_2 is not securely stored, it can threaten underground sources of drinking water, contaminate ecosystems, cause pressure interference or integrity problems for other wells in the area, or contribute to unintended atmospheric emissions, undermining the climate mitigation goals of CCUS. As such, regulatory frameworks for CO_2 geological storage must address a range of environmental concerns. In the meantime, environmental protection gives policymakers the public policy motivation to put CCS-specific laws in place (Dixon et al., 2015).

Moreover, incorporating environmental integrity into the regulatory framework not only protects the environment but also builds public trust in CCUS technologies. Clear and robust regulations create confidence that governmental oversight will ensure CO_2 geological storage is a safe, effective solution for addressing climate change. Without such regulations, CCUS projects may face public opposition, which could hinder their large-scale implementation and reduce their potential to contribute to global decarbonisation efforts. Thus, ensuring environmental integrity through well-designed regulations is essential for the success and widespread acceptance of CO_2 geological storage as a key climate mitigation strategy. This approach helps achieve beneficial outcomes from public and private investments, demonstrates the permanence of storage, ensures consistency across projects, and facilitates international acceptance of sequestration data.

1.3 Purpose of this report

Although China has some existing laws governing CO_2 injection, it is yet to establish a dedicated regulatory framework for CO_2 geological storage. Global practices can provide valuable guidance. The European Union and the United States have already developed comprehensive regulations for CO_2 geological storage that emphasise environmental integrity. Additionally, several international research organisations have formulated recommendations and guidelines on the matter. Drawing on these global experiences, China has an opportunity to craft its own regulatory framework that ensures environmental protection and fosters public trust in CCUS within and outside China. By analysing the key elements of existing regulations and identifying gaps in China's current regulatory framework, this report presents recommendations for the country to develop its own regulations for CO_2 geological storage in an environmentally responsible and sustainable manner.

[1] In this paper, we use the term CCUS instead of CCS, as CCUS is the more commonly used and officially recognised term in China. The Administrative Centre for China's Agenda 21 has published technology development roadmaps to guide the advancement of CCUS in the country.

[2] https://www.gov.cn/zhengce/zhengceku/202308/content_6899582.htm

[3] https://www.ndrc.gov.cn/xxgk/zcfb/tz/202404/t20240416_1365681.html

2.0 GLOBAL REVIEW

Environmental integrity serves as the cornerstone of an effective CO_2 geological storage project, both from the perspective of achieving decarbonisation and ensuring carbon market integrity. Over the past two decades, governments and research institutions have been actively developing related regulations, guidelines, and recommendations in this field (Table 1). The most notable regulatory pieces include the US EPA's Underground Injection Control (UIC) Program Class VI Rules (40 CFR Part 146 Subpart H) and the EU Directive 2009/31/EC (also known as the EU CCS Directive). While Canada and Australia have developed equally detailed regulatory regimes for CCUS, these frameworks are generally less centralised and not as longstanding as those in the US and EU. In Canada, regulatory authority is primarily held at the provincial level, and in Australia, CCS is regulated through a mix of Commonwealth and state legislation.

Moreover, the US and EU are home to many of the world's leading industrial-scale CCUS projects (GCCSI, 2024). In addition, International Standard Organization Technical Committee 265 (ISO TC 265) has developed standards and published technical reports addressing the full range of activities included in the CCUS chain from capture through transportation and ultimate geological storage of CO_2 streams. Research organisations such as the Environmental Defense Fund (EDF), the World Resources Institute (WRI), and the International Energy Agency (IEA) have developed guidance or best practices for regulating carbon storage activities to ensure environmental integrity. For instance, Peltz et al. (2022) developed three key pillars of the environmental integrity of a CO_2 geological storage project: preventing CO_2 leakage into the atmosphere, avoiding groundwater contamination, and minimising the risk of significant earthquakes, supported by a comprehensive list of technical considerations to support the three principles. These literature resources served as the foundation for this report.[4]

Table 1 - Sample regulatory literature for environmental issues of CO_2 geological storage activities (Compiled by author)

	DOCUMENT NAME	SOURCE	YEAR
Legislation	Underground Injection Control (UIC) Program Class VI Rules (40 CFR Part 146 Subpart H)	US EPA	2010
	The EU Directive on the Geological Storage of Carbon Dioxide (2009/31/EC)	European Parliament and Council of the European Union	2009
	The UK Energy Act	UK Government	2008
	Offshore Petroleum and Greenhouse Gas Storage Act 2006	Australian Government	2006
Standards	ISO 27914:2017 Carbon dioxide capture, transportation and geological storage — Geological storage	International Organization for Standardization	2017
	ISO 27916:2019 Carbon dioxide capture, transportation and geological storage — Carbon dioxide storage using enhanced oil recovery (CO_2-EOR)	International Organization for Standardization	2019
Third-Party Guidance	Legal and Regulatory Frameworks for CCUS	International Energy Agency	2022
	Strategies for Attaining CO_2 Sequestration with Environmental Integrity	Peltz et al.	2022
	Guidelines for Carbon Dioxide Capture, Transport, and Storage.	World Resources Institute	2008

[4] The table doesn't present a comprehensive list of carbon storage-related legislations. For instance, Brazil enacted the Fuels of the Future Bill in October 2024 to regulate CCS activities, while the Malaysian legislation has passed the Senate and is now awaiting royal assent. The framework nature of the Malaysian legislation is like the nature of the EU CCS Directive. This table only serves as the foundation for this study.

This section will begin by explaining why major CCUS countries or nations develop standalone regulations for CO_2 geological storage projects, presenting the key technical considerations related to maintaining environmental integrity in storage activities. It will primarily draw on the technical recommendations from the literature referenced in Table 1. Furthermore, it will highlight how these technical considerations are defined or addressed within existing regulatory frameworks, with direct references to Chinese regulators and regulatory researchers. This comparative analysis aims to provide the Chinese audience with a clearer understanding of how standalone regulations for CO_2 geological storage are structured and implemented.

This paper primarily focuses on environmental issues related to onshore geological storage for two main reasons:

1. Offshore environmental protection is regulated under a different framework and involves greater complexity, and
2. The majority of CCUS projects in China are currently being developed onshore. However, this paper could provide the foundation for a more expansive report that includes the offshore.

2.1 The US and EU's approaches to regulate CO_2 geological storage

CO_2 geological storage involves the injection of carbon dioxide into deep geological formations for long-term storage, which introduces specific environmental risks, such as CO_2 leakage, groundwater contamination, seismic activity, and interference or harm to other wells in the area. Furthermore, as a long-term solution, CO_2 must be securely stored permanently, requiring site stability assessments, continuous monitoring during operations, and post-injection care and containment assurance to confirm the integrity of storage sites over time. A well-defined regulatory framework is crucial to provide clarity on operator responsibilities and ensure that operators are financially accountable for any potential environmental damage or leakage. Given these unique challenges and issues, a dedicated regulatory framework for CO_2 geological storage would likely be more effective than simply incorporating the relevant requirements into existing regulations. This tailored framework can specifically address the unique risks and long-term stewardship requirements of CO_2 storage, ensuring safety, environmental protection, and regulatory certainty.

In the US, the EPA Class VI Rule was developed under the Safe Drinking Water Act[5], which governs all underground injection activities except for natural gas storage and certain hydraulic fracturing operations through the UIC Program. While the UIC Program's authority is grounded in the protection of underground sources of drinking water, the Class VI rule incorporates comprehensive requirements designed to ensure permanence of CO_2 storage. The Class VI Rule was specifically designed to regulate CO_2 injection and storage, incorporating requirements for site characterisation, well design and construction, testing and monitoring, operating, plugging, emergency response, reporting, and financial responsibility. Storage operators are also subject to other US environmental laws, including the National Environmental Policy Act, the Clean Air Act, and the Clean Water Act, which helps ensure a holistic approach to environmental protection if they are federally funded or have capture operations. (Table 2).

Table 2 - Sample authorities related to CO_2 sequestration (Adopted from EPA)[6]

AUTHORITY	ACTION(S) REQUIRED	AFFECTED MEDIUM	AUTHORISING/IMPLEMENTING AGENCY
Clean Air Act	Developing Monitoring, Reporting, and Verification (MRV) plans under the Greenhouse Gas (GHG) Reporting Rule (onshore and offshore)	Air	US EPA, Office of Air and Radiation, Office of Atmospheric Protection, verification (MRV) plans under the Climate Change Division
Clean Water Act	National Pollutant Discharge Elimination System permitting (onshore and in offshore state waters)	Waters of the US	US EPA, Office of Wastewater Management
National Environmental Policy Act (NEPA)	Environmental Assessments and Environmental Impact Statements for major federal actions	Air, surface (e.g., emission source, pipeline), subsurface	Agencies responsible for permitting major federal actions

[5] In October 2007, the EPA announced plans to propose regulations for CO_2 geologic sequestration projects to ensure consistent permitting. Public workshops were held to inform the regulatory process, and the proposed Class VI wells rule was published in July 2008, with a comment period closing on 24 December 2008. The rule became effective on 10 December 2010. On 7 September 2011, after a 270-day period for states to apply for primacy, the EPA retained direct implementation of the Class VI program in all states, tribes, and territories. Since then, North Dakota, Wyoming, Louisiana, West Virginia, Arizona, and Texas have received primacy to implement the Class VI program.

[6] https://www.epa.gov/system/files/documents/2023-10/regulatory-and-statutory-authorities-relevant-to-carbon-capture-and-sequestration-ccs-projects.pdf. In the US, carbon storage regulatory frameworks operate as a hybrid of state and federal law, reflecting the significant independence of subnational jurisdictions. States play a crucial role, particularly in determining property rights and liability issues, while the federal government maintains overall oversight through mechanisms such as primacy. This collaborative regulatory model allows for flexibility tailored to local conditions while ensuring consistent, nationwide protection of environmental and public health interests.

Beyond regulatory compliance, operators seeking to claim tax incentives under Section 45Q must demonstrate secure CO_2 storage as required by guidance and regulations from the Internal Revenue Service (IRS), which administers the 45Q tax credits. The IRS guidance, which has been periodically updated, establishes a formal definition for "demonstration of secure geological storage", relying primarily on Subpart RR reporting under the Greenhouse Gas Reporting Program (GHGRP) while using ISO 27916 as an alternative in cases where CO_2 is used for enhanced oil recovery. Under current regulations, Class VI operators are required to develop and follow an EPA-approved monitoring, reporting, and verification (MRV) plan under Subpart RR and report against that plan into the GHGRP system. These measures ensure both regulatory compliance and environmental integrity, while supporting the transparency and financial viability of CCUS projects.

Finally, while not reviewed substantively in this paper, an important and valuable resource was adopted in September of 2025 by the US Interstate Oil & Gas Compact Commission (IOGCC), a multi-state government entity representing 31 US states, federal agencies, and Canadian affiliates, established to define best practices for the regulation of oil, gas, and other related energy issues. IOGCC's leadership (state governors and/or their official representatives) adopted a "Model Statute on Geologic Sequestration of Carbon Dioxide."[7] The model statue and guidance[8] are comprehensive, addressing everything from jurisdiction and definitions to induced seismicity, and are designed to guide states in developing regulatory frameworks that complement the EPA Class VI permitting program and augment it by addressing the areas outside the scope of the UIC program, including subsurface and CO_2 ownership rights.

2.2 Technical recommendations

2.2.1 Siting (Demonstration of suitable geologic system)

The stage of siting is to demonstrate that the geologic setting at the proposed site is suitable for CO_2 sequestration. Proper site selection and characterisation are of utmost importance for ensuring the long-term environmental integrity of CO_2 storage. The IPCC stated that with proper site selection and effective management, CO_2 can be permanently isolated from the atmosphere in geological storage sites (IPCC, 2023). Virtually all regulatory frameworks related to geological CO_2 storage mandate a thorough process of site selection and characterisation (Table 3). These recommended or required practices include detailed geological surveys, developing a subsurface model using site-specific data, verifying confining zones, identifying and assessing potential leakage pathways (such as existing wells), and mapping and evaluating faults and fractures. The US EPA's "UIC Program Class VI Well Site Characterization Guidance (2013)" provides a comprehensive framework for site selection and characterisation, consistent with the requirements of 40 CFR Part 146 Subpart H. The guidance is organised into three key components: pre-construction activities, data synthesis, and pre-operation activities. Pre-construction activities involve gathering critical data on injection and confining zones, delineating the Area of Review, and establishing baseline site characteristics, which are prerequisites for applying for a Class VI permit. Then, the collected data is analysed to demonstrate site suitability by addressing regulatory requirements, including injectivity, storage capacity, and containment integrity. Pre-operation activities include well construction, mechanical integrity testing, formation testing, and CO_2 plume modelling are all necessary to secure authorisation for injection.

Table 3 - Site selection and characterisation requirements under some sample regulations (Compiled by author)

REGULATION/GUIDANCE	KEY REQUIREMENTS
US 40 CFR Part 146 Subpart H	Require comprehensive site characterisation as part of the permitting process for CO_2 injection. This process includes geological, geophysical, and geochemical assessments to determine the suitability of the site for CO_2 storage. Key Factors that must be evaluated for an injection zone(s) and confining zones (40 CFR &146.83). • Injection Zone: Sufficient areal extent, thickness, porosity, and permeability. • Confining Zone: Free of transmissive faults or fractures; sufficient areal extent and integrity; able to withstand injection pressures and act as barrier to fluid movement.
EU Directive 2009/31/EC	• Comprehensive assessment required to show no significant risk of leakage or environmental/ health risks (Article 4). • Thorough characterisation of the potential storage complex and surrounding area, including geological structure, hydrogeology, geochemistry, potential leakage pathways, etc (Annex I).
UK Energy Act 2008 (The Storage of Carbon Dioxide (Licensing etc.) Regulations 2010)[9]	The applicants are required to submit a Site Characterisation Review Report for the appraisal phase requirements (Guidance on Applications for a Carbon Storage Permit). The site characterisation criteria are based on the Annex I to the EU CCS Directive.

The ultimate purpose of the site selection and characterisation is to demonstrate that the selected storage reservoirs have sufficient capacity and are securely sealed by confining systems to prevent CO_2 leakage.

According to WRI (2008), three key factors determine reservoir suitability:

- The effectiveness of primary confining zones in preventing vertical CO_2 migration across the entire expected CO_2 migration area,
- The injectivity or the rate at which CO_2 can be injected into the reservoir, and
- The estimated storage capacity of the storage reservoir.

WRI (2008) also provided guidance on potential data sources and analytical methods to evaluate these factors (Table 4). Although specific requirements and the regulatory stages for these assessments may differ between jurisdictions, the fundamental objective of all regulatory frameworks remains the same: to ensure comprehensive site selection and characterisation, confirming the target reservoir's suitability for safe and effective long-term CO_2 storage.

Table 4 - Examples of Information and Data Sources for Characterisation of Storage Sites (Adopted from WRI 2008)

ATTRIBUTE OF FORMATION	KEY INFORMATION	BASIC DATA SOURCES	BASIC ANALYSIS	ADVANCED ANALYSIS
Proof of functional confining zone(s)	• Presence, number, continuity, thickness, and character of confining zone • Fault azimuth and offset • Surface and formation well density • Well construction and plugging history	• Cores • Well logs • Structure maps • In-situ stress • Well location maps • Well drilling and plugging records • 3-D seismic volumes	• Stratigraphic analysis • Reservoir models • Simple calculation • Mohr-Coulomb failure calculation • Core analysis • Well location verification (e.g., cement bonding logs)	• Aeromagnetic surveys • Capillary entry pressure tests • Fault segmentation analysis • Advanced simulation
Injectivity	• Thickness, porosity, and permeability • Production/flow rate • Delivery rate connectivity	• Conventional core analysis • Well logs • Production history • Injection or leak-off tests • Pressure	• Stratigraphic analysis • Population of static geological models • Core plug analysis • Conventional simulation • Well pump tests/ injection tests	• Detailed stratigraphic characterisation • Hydro-fracture analysis • Special core analysis
Capacity	• Accessible pore volume • Lateral extent • Area of injection • Trapping mechanism	• Conventional core analysis • Well logs • Structure maps • 3-D seismic data	• Stratigraphic analysis • Static geomodels • Simple calculation • Conventional simulation • 3-D seismic mapping	• Advanced simulation • Fill-spill analysis • Special core analysis

[7] https://oklahoma.gov/content/dam/ok/en/iogcc/documents/committees-councils/legal/Model%20Statutes.pdf
[8] https://oklahoma.gov/content/dam/ok/en/iogcc/documents/committees-councils/legal/CCSModelStatute09.24.25.pdf

[9] The Energy Act 2008 provides for a licencing regime that governs the offshore storage of carbon dioxide. It forms part of the transposition into UK law of EU Directive 2009/31/EC on the geological storage of carbon dioxide. The Carbon Dioxide (Licensing etc.) Regulations 2010 (SI 2010/2221), which transpose many other requirements of the directive, came into force on 1 October 2010.

During this stage, storage sites must also undergo a thorough assessment to identify potential leakage pathways within the Area of Review (AoR), including faults, fractures, and wells, in order to ensure the secure containment of CO_2.[10] Regulations should mandate the identification and risk assessment, including assessment of need for monitoring of these pathways, permanent closure or plugging as may be the case with inactive wellbores, and modifications to operating wells if the storage interval is not properly isolated. The EU Directive 2009/31/EC includes leakage pathway assessment as a key component of hazard characterisation (Annex I 3.3.1). Both the IRS Notice and the EU Directive emphasise the necessity of ongoing monitoring of potential leakage pathways in alignment with a comprehensive monitoring plan. ISO 27914 (geologic storage) and ISO 27916 (storage in association with CO_2-EOR) also require leakage pathway assessments.

LEARNINGS REGARDING MONITORING WELLS FROM US EXPERIENCE

The ADM Decatur CCS project in Illinois is a commercial-scale initiative demonstrating long-term CO_2 sequestration. Capturing CO_2 from an ethanol plant, the project injects the captured CO_2 more than 5,550 feet underground, employing an extensive monitoring well system to ensure secure containment. The Illinois Industrial Carbon Capture and Storage project, which has a megaton-scale capacity, initially deployed two deep monitoring wells for downhole monitoring and periodic fluid sampling. These wells are situated more than 5,000 feet below ground level.[10]

In 2023, corrosion was detected in tubing within one of the deep monitoring wells at 5,000 feet, leading to its plugging in October 2023.[11] In March 2024, fluid movement was discovered at a similar depth. Later, a third-party laboratory test suggested that no CO_2 was present in that fluid and fluid movement had stopped.[12] At no time during these developments was there an impact on surface or groundwater sources, nor any threats to public health.[13] Since the incident, ADM has been working closely with the US EPA; in September 2024, ADM temporarily halted CO_2 injections.[14]

Based on further analysis, ADM modified its monitoring strategy. It established separate, dedicated wells for sampling above and below the CO_2 confining zone. Additionally, it replaced certain subsurface equipment and utilised 25 chrome steel in major components to enhance corrosion resistance.[15] On August 29, 2025, ADM resumed injection.[16]

The ADM Decatur experience underscores the importance of a comprehensive monitoring strategy and proactive intervention based on early warning signs. ADM's monitoring system, incorporating downhole pressure gauges and fluid sampling, played a crucial role in detecting these integrity issues.

2.2.2 Well construction and completion

CO_2 injection wells must be constructed and completed to prevent leaks and unauthorised fluid movement. Regulations should also ensure that construction materials are compatible with the injected fluids. The US 40 CFR Part 146 Subpart H § 146.86 outlines the requirements for Class VI injection wells. These wells must prevent fluid movement into drinking water zone or other unauthorised zones and be designed for continuous monitoring of the injection process. The casing and cementing must meet strict standards to ensure structural integrity throughout the project's lifespan. Based on this regulatory requirement, the US EPA has developed a comprehensive guide, "UIC Program Class VI Well Construction Guidance (2012)," for Class VI injection well owners and operators, detailing steps available to comply with these requirements. This document also outlines the criteria the UIC Program Director will assess when reviewing a Class VI injection well permit application. ISO 27914 provides similar requirements that address materials of construction, design, tubulars, casing, cementing, corrosion, groundwater protection, testing, integrity, and plugging.

2.2.3 Operations

CO_2 geologic storage projects require long-term assurance of operational containment, which is achieved through engineering data, reservoir management, and well integrity monitoring. Regulations should ensure injection safety, maintain mechanical integrity, and allow for flexible compliance methods. Under US 40 CFR § 146.88, Class VI injection wells must undergo pressure fall-off, pump or injectivity tests to verify hydrogeologic characteristics before operation. These tests may be observed by regulators. During normal operations, injection pressure must not exceed 90% of the fracture pressure to prevent fractures and protect USDWs. Continuous monitoring of injection pressure, CO_2 stream rate, temperature, and annular pressure is required. Alarms and automatic shut-off systems must be in place to quickly respond to unsafe conditions. If mechanical integrity is compromised or a shutdown occurs, injection must cease, an investigation must be conducted, and the Director must be notified within 24 hours. Injection may only resume once integrity is restored and verified. ISO 27914 also provides detailed operating requirements.

2.2.4 Closure and post-closure

The key technical requirements for the period of closure and post-closure include injection well plugging, post-injection site care, and site closure certification. Injection and monitoring well plugging are crucial to prevent fluid migration. Before the approval of site closure, wells must be plugged in accordance with regulations and an updated, approved plugging plan that adheres to industry standards and ensures that fluid movement into or between unauthorised zones is prevented through the well or along its exterior. The provisions for injection well plugging under US 40 CFR § 146.92 require that before plugging, operators must flush the well with a buffer fluid, determine bottomhole reservoir pressure, and perform a final external mechanical integrity test. A Director-approved well plugging plan, submitted with the permit application, must detail testing methods, plug specifications (type, number, placement, and materials), and placement procedures. These requirements ensure a controlled, documented process to safeguard drinking water and enable regulatory oversight. The EU Directive 2009/31/EC does not have specific language on well plugging, but ISO 27914 does have requirements similar to the Class VI requirements.

Post-Injection Site Care (PISC) involves monitoring the evolving CO_2 plume and its diffusion of formation pressure to ensure environmental integrity between the cessation of injection and official site closure. Post-injection monitoring determines if the CO_2 plume remains in the target reservoir and behaves as predicted. It provides a comprehensive understanding of the site, conducts conformance assessments, and matches historical data. US 40 CFR § 146.93 requires Class VI well owners or operators to develop, maintain, and adhere to a post-injection site care and closure plan approved by the Director. Upon injection cessation, operators must either amend the plan or demonstrate its continued adequacy with monitoring data and modelling results, requiring Director approval and permit modification compliance. The EU CCS Directive defines the "post-injection period" as the closure period, mandating post-closure monitoring to detect CO_2 migration or leakage and address environmental risks (Article 17(2)). After injection ceases, US regulations require monitoring for at least 50 years or an alternative timeframe approved by the Director, while the EU Directive mandates a minimum 20-year monitoring period. ISO 27914 and ISO 27916 both include post-injection requirements for monitoring and decommissioning.

Site closure certification can be granted when there is a clear demonstration that the CO_2 is securely contained within the confining zone and poses no risk to public health and the environment. During the closure period, depending on the specific characteristics of the storage reservoir, the pressure of the injected CO_2 either stabilises or starts dissipating to the extent that it can be proven that the injected CO_2 no longer endangers human health and the environment.

Under the EU CCS Directive (2009/31/EC), a CO_2 storage site may be closed if the conditions outlined in the storage permit are met, upon authorisation from the competent authority, or if the authority decides to withdraw the permit (Article 17). After closure,

[10] https://www.adm.com/globalassets/standalone-pages/carbon-capture-and-storage/in-depth--monitoring-well-developments.pdf
[11] https://www.adm.com/globalassets/summary-monitoring-well-developments.pdf
[12,13] Ibid.
[14] https://www.adm.com/globalassets/standalone-pages/carbon-capture-and-storage/adm-statement---8.29.25.pdf
[15,16] Ibid.

the operator remains responsible for maintenance, monitoring, control, reporting, and corrective measures as specified in the approved post-closure plan, ensuring long-term CO_2 containment. The operator must continue monitoring the site for a minimum of 20 years, unless the competent authority determines that earlier evidence proves permanent containment (Article 18). Transfer of responsibility to the competent authority occurs only when the operator demonstrates that the stored CO_2 is permanently contained, no significant leakage risks exist, and the site is evolving toward long-term stability. This must be supported by monitoring data and a closure report.

In the US, states have addressed long-term responsibility and liability in variable ways. While some states, such as Texas, remain silent on transfer of responsibility or liability, other states like Colorado and New Mexico, as well as the Interstate Oil and Gas Compact Commission[17], have taken approaches that allow for the transfer of responsibility, with key exceptions. These include violation of duty, provision of deficient or erroneous information, responsibility for fluid migration that threatens a source of drinking water, or insufficient funds available in escrow or storage trust funds. These measures collectively ensure that CO_2 storage sites remain secure, environmentally sound, and compliant with long-term climate goals, while also avoiding unduly broad responsibility relief that reduces public trust. ISO 27914 and ISO 27916 include similar requirements to demonstrate the absence of leakage, containment of injected CO_2, plugging and decommissioning of wells and equipment, and verification of storage performance predictions.

2.2.5 Other cross-cutting issues

(1) CO_2 stream characterisation

CO_2 streams intended for geological storage should overwhelmingly consist of carbon dioxide with minimal impurities to maintain operational integrity and minimise risks to the environment and public health. For example, water in the CO_2 stream can form carbonic acid, which corrodes steel and other materials used in well construction. To address this, operators must regularly monitor the CO_2 composition to ensure regulatory compliance. The EU Directive 2009/31/EC specifies in Article 12 that only streams "overwhelmingly" composed of carbon dioxide are eligible for injection into storage sites. Similarly, US regulations under CFR Section 146.90(a) require project owners or operators to analyse the chemical and physical properties of the CO_2 stream before injection and periodically throughout the project's lifecycle. The ISO standards have similar stream composition requirements (ISO, 2020). These measures ensure the safe and effective operation of geological storage systems.

(2) Area of review delineation and modelling

According to the US 40 CFR § 146.84, the AoR is defined as "the region surrounding a geologic sequestration site where USDWs could be at risk from injection activities." Operators are required to delineate the AoR using computational modelling that simulates the physical and chemical behaviour of the injected CO_2 stream and periodically reassess it to address potential risks. To support compliance with these regulations, the US EPA has published a detailed guidance document titled "UIC Program Class VI Well Area of Review Evaluation and Corrective Action Guidance (2013)." This 96-page document provides comprehensive instructions on modelling techniques for AoR delineation, the circumstances that necessitate AoR reevaluation, and methods for conducting such evaluations. It also includes guidance on identifying, assessing, and addressing artificial penetrations within the AoR that could require corrective action. While the EU Directive 2009/31/EC does not explicitly use the term "Area of Review," it includes provisions for managing, monitoring, and assessing storage sites. Although "storage sites" has a broader definition in EU's CCS Directive based on the Guidance Document, these provisions encompass the review and modelling of CO_2 migration and plume behaviour to ensure the long-term containment of CO_2 and the protection of the environment and public health (European Commission, 2024). ISO 27914 also uses the Area of Review concept, but ISO 27916 uses EOR complex and EOR project boundaries with similar requirements for containment assurance. Bump & Hovorka (2024) suggest that when considering multiple sites and cumulative impacts, particularly due to pressure front movement, it might be desirable to conduct a combined AOR, which may have a greater extent than individual project AORs. This is an emerging issue gaining traction in the US and of importance as the number of storage sites in close proximity increase.

(3) Testing and monitoring plans

A testing and monitoring plan, based on a formal risk assessment, is crucial for ensuring the environmental integrity of carbon storage projects. This plan should include both direct and indirect monitoring methods, with a dynamic and flexible approach that adapts to changing project needs (Hovorka, 2024). Annex II of the EU CCS Directive 2009/31/EC mandates monitoring plans for CO_2 storage projects based on thorough risk assessments and regular updates. The plan specifies monitored parameters, technologies, locations, and sampling frequencies, including CO_2 flow rates, pressures, temperatures, and chemical composition. It combines technologies to detect CO_2 migration and refine numerical models. Data from monitoring recalibrates models, updates risk assessments, and adjusts the plan. Post-closure monitoring builds on operational data for long-term information on project closure and long-term monitoring. This approach ensures safe and effective long-term CO_2 storage by continuously assessing and adapting to project conditions and risks. Similarly, the US 40 CFR § 146.90 requires owners or operators to develop a comprehensive testing and monitoring plan as part of the permit application, maintain it throughout the project, and regularly review and amend it as needed.

(4) Demonstration and verification of secure storage

Secure CO_2 storage requires a comprehensive demonstration based on geological data, monitoring activities, and fluid-flow modelling to confirm the absence of leaks over a meaningful timeframe. Both the US Class VI Rules and the EU CCS Directive mandate plans for baseline, operational, and post-closure monitoring (see "Testing and Monitoring Plans"). Peltz et al., (2022) suggests that secure storage can be demonstrated by aligning modelled predictions with observed behaviour, ensuring plume extent and pressure changes match expectations. Evidence must confirm no leakage beyond the confining zone, with continuous monitoring and geological assessments guiding future migration predictions. Additionally, verifying the structural integrity of wells is essential to prevent leaks and maintain overall site security. ISO 27914 and ISO 27916 have similar requirements for demonstrating and maintaining containment assurance.

(5) Emergency response plans

Emergencies can arise during industrial activities, and proactive planning can minimise environmental, public health, safety, and reputational damage. Project operators must develop, update, and adhere to a risk-based emergency and remedial response plan including equipment, training and drilling local emergency responders. Class VI injection wells must develop, implement, and maintain an emergency response plan as part of permit application under 40 CFR § 146.94. The Emergency Response Plans requirements are embedded in the EU Directive 2009/31/EC within the framework for risk management and monitoring. For example, operators must submit a corrective measures plan for storage permits in Article 7 and immediately notify the competent authority upon detecting a leakage or significant irregularity. Corrective measures must be implemented according to a pre-approved plan in Article 16.

(6) Financial assurance

The financial assurance is required to cover costs related to site closure, monitoring, and post-closure care. The owner or operator must demonstrate this financial assurance before beginning injection operations. The financial mechanism must guarantee that the required funds will be available for the full closure and Post Injection Site Care period. For example, The US 40 CFR § 146.85(a&b) specifies that the financial assurance must cover the entire period for which the owner or operator is responsible, including any extended post-injection care period. Article 19 of EU Directive 2009/31/EC requires CO_2 storage site operators to provide proof of adequate financial security to meet all obligations under the storage permit. This security must be valid and effective before injection begins and cover site closure, post-closure, and compliance with emissions trading.

[17] Ibid.

3.0 CHINA REVIEW

3.1 China's existing environmental legal and regulatory framework for CO_2 geological storage

Although China has not established a specific regulatory framework for CO_2 geological storage, the country has established certain laws and regulations that can regulate certain activities from the perspective of environment integrity. The current framework is underpinned by several key legislative and regulatory documents that provide a foundation for managing the complexities of CO_2 storage. These include overarching environmental laws, specific regulations targeting geological activities, and guidelines tailored to the emerging field of CCUS. In addition, China is in the process of developing its own equivalent of ISO standards by directly adapting international standards to the Chinese context. This section first reviews the key documents that may govern CO_2 geological storage in China.

(1) Environmental Protection Law (Established in 1989, amended in 2014)[18]

China's Environmental Protection Law (EPL), originally enacted in 1989 and significantly amended in 2014, serves as the foundation for the nation's environmental legal framework. It establishes that willfully harming the environment is illegal and mandates compliance with environmental impact assessment (EIA) requirements. The EPL is primarily enforced through specific laws addressing air, water, solid waste, and other areas. Notably, the 2014 amendments introduced stricter penalties for polluters, enhanced transparency, and increased public participation in environmental governance. These provisions have strengthened the legal basis for environmental regulations governing projects like CCUS, including geological activities.

(2) Water Pollution Prevention and Control Law (Established in 1984, amended in 2008 and 2017)

The Water Pollution Prevention and Control Law includes provisions to safeguard drinking water sources, encompassing both surface water and groundwater. It explicitly addresses activities such as underground engineering, prospecting, mining, and other subsurface operations. The law also establishes rules on pollution liability, dispute resolution, and the management of water resource exploitation. However, it does not apply to brine, mineral, or geothermal groundwater — therefore excluding saline aquifers from its scope. Nonetheless, the law would be applicable in cases where CO_2 leakage from a geological storage reservoir impacts drinking water sources, or where brine migration induced by CO_2 injection affects the quality of potable groundwater.

(3) Environmental Impact Assessment Law (Established in 2002, amended in 2018)

This law establishes procedures for evaluating the environmental impacts of development activities. For construction projects, the environmental impact report must include the following elements: an overview of the project, a description of the surrounding environment, predictions and evaluations of potential environmental impacts, proposed environmental protection measures with technical and economic justification, an analysis of the economic benefits and costs of the environmental impacts, recommendations for environmental monitoring, and a conclusion summarising the appraisal of environmental impacts. Public participation is a mandatory part of the EIA approval process for both plans and projects. As the law outlines general requirements, MEE provides more detailed guidance to facilitate public participation in project-level assessments. Notably, EIA approval is a prerequisite for project approval. For CCUS — including carbon geological storage — compliance with EIA procedures is required.

(4) Mineral Resources Law (Established in 1986, amended in 2020)[19]

This law governs the exploration and utilisation of subsurface resources. It includes provisions for sustainable resource management and the protection of geological formations from potential adverse impacts. For example, the Article 32 indicates that "in mining mineral resources, a mining enterprise or individual must observe the legal provisions on environmental protection to prevent pollution of the environment." The key issue is whether underground pore space is defined as a mineral resource in China's legal terms or if it will be included. If it is, then injecting CO_2 into the pore space will be considered a type of activity under this law.

(5) Technical Guidelines for Environmental Impact Assessment – Groundwater Environment (Established in 2011, amended in 2016)[20]

This standard is formulated to implement the Environmental Protection Law, the Law on the Prevention and Control of Water Pollution, and the Law on Environmental Impact Assessment, aiming to standardise and guide groundwater environmental impact assessments, protect the environment, and prevent groundwater pollution. It outlines the principles, content, methods, mechanisms, and requirements for assessing environmental impacts on groundwater. The standard applies to environmental impact assessments for construction projects that use groundwater as a water supply source or may affect the groundwater environment, which should include CO_2 storage activities.

(6) Technical Guideline on Environmental Risk Assessment for Carbon Dioxide Capture, Utilisation and Storage (on Trial), 2016

In 2016, the Technical Guideline for Environmental Risk Assessment of Carbon Dioxide Capture, Utilisation, and Storage (Trial) was issued by the Department of Science, Technology, and Standards under the Ministry of Environmental Protection of China. This Guideline serves as a technical reference for assessing environmental risks associated with CCUS. It also provides guidance for conducting environmental risk assessments for newly constructed or expanded projects involving CO_2 capture, geological utilisation, and geological storage on land.

(7) Chinese equivalent – ISO Standards for Geological Storage (under preparation)

In December 2023, the Standardisation Administration of China announced plans to adopt ISO-based CCUS standards tailed to the Chinese context. These include ISO 27914:2017(Geological Storage), ISO 27916:2019 (Storage using EOR), ISO27917:2017 (Vocabulary – Cross cutting terms), ISO 27919-1:2018 (Performance evaluation methods for post-combustion CO_2 capture integrated with power plants), ISO 27919-2:2021 (Evaluation procedures to assure and maintain stable performance of post-combustion CO_2 capture).

The draft geological storage standard, registered under Project No. 20232501-T-469, was jointly developed by the Wuhan Institute of Rock and Soil Mechanics of the Chinese Academy of Sciences, the China National Institute of Standardisation, and the Chinese Geological Survey, among others.[21] It is primarily based on ISO 27914:2017 and was released for public comment on January 17, 2025, with a feedback deadline of February 28, 2025. The draft closely follows the framework of ISO 27914 and addresses nearly all key technical components outlined in Section 2 of this paper. The draft comprises ten sections, mainly including Site Screening, Selection & Characterisation, Risk Management, Well Infrastructure, CO_2 Storage Site Injection Operations, Monitoring and Verification, and Site Closure.

Similarly, the draft EOR standard (Project No. 20232500-T-469) was developed by the CNPC Research Institute for Environment and Safety, the China National Institute of Standardization, and the Chinese Geological Survey, among others.[22] Based on ISO 27916:2019, the draft was released for public comment on February 11, 2025. It focuses on 1) Ensuring the safe and long-term containment of CO_2 within the EOR complex; 2) Addressing potential leakage pathways from the EOR complex; 3) Preventing CO_2 losses from wells, equipment, or other onsite facilities. Once stakeholder feedback is incorporated, the final versions of both standards will be published. Project developers are recommended to follow these standards — particularly those for geological storage — to ensure alignment with internationally recognised best practices.

Overall, these legal and regulatory frameworks collectively serve as a foundational basis for regulating CO_2 geological storage activities in China. However, they do not fully address the unique characteristics and technical requirements of geological storage — such as site selection and characterisation, post-closure site care, and long-term testing and monitoring — as outlined in Section 2.2. These gaps highlight the need for tailored regulations that reflect the specific risks and operational complexities associated with carbon storage projects.

3.2 Case studies of CO_2 geological storage projects in China

China has actively pursued the development of CO_2 geological storage through several pilot and demonstration projects. These projects also provide valuable insights into the practical implementation of CO_2 storage under diverse geological and industrial conditions. Three representative case studies are outlined below.

[18] https://www.mee.gov.cn/ywgz/fgbz/fl/201404/t20140425_271040.shtml (http://www.asianlii.org/cn/legis/cen/laws/eplotproc564/#:~:text=%5BArticle%202%5D%20The%20function%20of,to%20create%20a%20clean%20and)

[19] https://www.gov.cn/yaowen/liebiao/202411/content_6985756.htm (https://english.mee.gov.cn/Resources/laws/envir_elatedlaws/200710/t20071009_109919.shtml)

[20] https://www.mee.gov.cn/ywgz/fgbz/bz/bzwb/other/pjjsdz/202203/t20220323_972428.shtml

[21] https://www.cnis.ac.cn/bydt/bzyjzq/gbyjzq/202501/P020250107352885899910.pdf

[22] https://www.cnis.ac.cn/bydt/bzyjzq/gbyjzq/202502/t20250211_59518.html

3.2.1 CNPC Jilin CCUS Demonstration Project

In 1999, CO_2 flooding test was carried out in Jilin Oilfield of CNPC. During the 6-year operation period, field injection tests were carried out in 2 wells for 3 times. In 2003, the industrial standard "Safety Technical Requirements for Carbon Dioxide Injection in Oil and Water Wells (SY/T 6565-2003)" was issued based on the above test results and which defined the safety requirements for the design, construction, operation and management of CO_2 injection in onshore oil and gas fields. This industrial standard provided the national best practice for safety issues while injecting CO_2 for oil production at that time. In 2014, Jilin Oilfield built a 100 ktpa full-process CCUS-EOR industrialisation demonstration project including capture, transportation, injection and production, re-purification and re-injection. Now, Jilin Oil Field is preparing an integrated million-ton-scale CCUS demonstration project.

3.2.2 Shenhua Ordos CCS Demonstration Project

The Shenhua Ordos CCS Demonstration Project, launched in 2011, is one of China's most prominent integrated CCS initiatives and the country's first geological CO_2 storage project. It captures CO_2 emissions from a coal-to-liquids production facility and stores approximately 100,000 tonnes of CO_2 annually in a deep saline aquifer within the Ordos Basin. Comprehensive site characterisation was conducted, involving detailed geological assessments such as seismic surveys, geological mapping, and hydrological modelling to evaluate the site's suitability based on global industry best practices. These efforts focused on assessing storage capacity, seal integrity, and isolation from potential leakage pathways. Advanced numerical simulations were used to predict CO_2 plume behaviour and pressure evolution within the reservoir over the long term (Zhang et al., 2016). A robust monitoring framework was also established, integrating technologies such as seismic imaging, and groundwater sampling. Real-time data systems were implemented to track plume migration, monitor reservoir pressure changes, and detect any signs of leakage. Regular data analysis enabled early risk identification and mitigation, aligning with international best practices (Zhao et al., 2017). Additionally, comprehensive emergency response plans were developed to manage potential leakage or operational incidents. Stakeholder engagement played a key role, with proactive communication of project risks and response strategies to local communities and regulatory bodies to ensure transparency and preparedness (吴秀章, 2013).

4.0 A PROPOSED PATHWAY FOR EFFECTIVELY REGULATING CHINA'S CO_2 GEOLOGICAL STORAGE ACTIVITIES

4.1 Lessons from international approaches

Overall, both the EU CCS Directive and the US 40 CFR Part 146 Subpart H Class VI permitting program share key similarities in their approach to carbon storage (Table 5). While the EU CCS Directive provides a broad, overarching framework for CCS development within the European Union, the US Class VI program offers a more detailed and specific regulatory approach in the United States, with a strong focus on subsurface integrity given the EPA's overarching authority is tied to protecting USDWs, rather than preventing atmospheric emissions.

It is also worth noting that the EU Directive only provides a framework for Member States to implement through national legislation. ISO 27914 and ISO 27916 provide very similar frameworks and were developed with the participation of China as a full member of ISO TC 265. Moreover, ISO standards have been adopted as regulations by China as demonstrated before.

Table 5 - Key regulatory requirements between the US EPA Class VI Well Rules and the EU CCS Directive (Compiled by author)

REGULATORY APPROACH FOR CO_2 GEOLOGICAL STORAGE - COMMON PRINCIPLES)

- **Site selection and characterisation:**
  - Comprehensive geological, geophysical, and geochemical assessments are required to evaluate site suitability, including storage capacity, seal integrity, and potential leakage pathways such as faults and fractures.
  - Risks to groundwater resources must be considered, and detailed site characterisation data is required for permit applications.
  - Site assessments must be supported by modelling and monitoring data to demonstrate CO_2 containment.
- **Area of review:**
  - An AOR must be defined around the injection site to evaluate environmental risks and identify and address natural and artificial penetrations that may impact the integrity of the storage zone. It may be important to consider pressure interactions among multi-well or cumulative storage sites that may require larger AOR sizes.
  - Computational modelling is used to simulate CO_2 plume migration and pressure behaviour, with periodic reevaluation based on updated data.
- **Monitoring and testing:**
  - Continuous monitoring of injection pressures, CO_2 plume behaviour, and the pressure front is required throughout the project.
  - Groundwater monitoring is essential for detecting contamination, and regular well integrity testing is mandatory.
  - Operators must develop and implement a comprehensive testing and monitoring plan, covering injection, post-injection, and post-closure phases.
  - Monitoring wells should be designed with appropriate materials and sited to avoid impacting the integrity of the storage project and regulations should include siting, construction, monitoring, and closure requirements for such wells.
- **Well construction and integrity:**
  - Wells must be constructed using materials and techniques that ensure mechanical integrity and compatibility with CO_2 and formation fluids.
  - Casing, cementing, and tubing must meet established standards, with pre-operation testing (e.g., pressure testing and mechanical integrity evaluations) required.
  - Regular inspections and maintenance are necessary to ensure long-term well integrity.
- **Induced seismicity management (Templeton et al., 2021):**
  - Conduct thorough preliminary evaluations of seismic risks by analysing geological conditions, historical seismicity, and operational parameters.
  - Develop detailed response and mitigation strategies.
  - Implement robust seismic monitoring systems to detect and analyse seismic events in real-time. Utilise the collected data to perform hazard evaluations and adapt operational protocols accordingly.
- **Corrective measures and risk management:**
  - Operators must identify, assess, and mitigate containment risks, including leakage pathways.
  - A corrective measures plan is required for responding to irregularities.
  - Corrective actions must be implemented promptly if risks are identified.
- **Post-injection site care and closure:**
  - Long-term monitoring is required after injection ceases.
  - Site closure plans must include well plugging, sealing, and continued monitoring.
  - Operators must submit and comply with approved post-injection site care and closure plans.
  - Monitoring requirements may be reduced if stability is demonstrated and all requirements for a defined demonstration of permanent, secure storage have been verifiably met.
- **Financial assurance:**
  - Operators must provide financial security to cover closure, post-closure monitoring, and corrective measures, ensuring funds are available for potential risks and liabilities.
  - Financial assurance must be established before operations, periodically adjusted, and remain valid until operator responsibility is released or transferred.
- **Public and Regulatory Oversight:**
  - Transparency and accountability are key, requiring operators to submit detailed reports and engage with regulatory authorities.
  - Regulatory approval is mandatory for major activities, with authorities responsible for reviewing, approving, and enforcing compliance.
  - Operators must maintain records and submit periodic reports to ensure oversight and regulatory adherence, including adoption of and reporting against an approved monitoring, reporting, and verification program.

4.2 Recommendations for the overall framework

(1) Develop dedicated legislation or regulations

Creating dedicated legislation or incorporating carbon storage-specific regulations into existing environmental or energy laws is essential to provide a clear, robust, and enforceable legal framework for deploying carbon storage effectively and safely. Additionally, defining the roles and responsibilities of government bodies is crucial for streamlining oversight, ensuring accountability, and coordinating actions across relevant stakeholders.

A dedicated CCUS law or regulations within existing frameworks would provide legal certainty for operators, regulators, and investors in China. It would clearly define the rules for site selection, permitting, monitoring, closure, and any other aspects necessary for a comprehensive CCUS program, such as financial responsibilities and long-term site stewardship. A program should also ensure public engagement in decision-making processes and support transparency in reports regarding the safety and security of storage, addressing concerns about environmental risks. Lastly, a formal CCS legal framework would enable harmonisation with international standards and practices, promoting collaboration in technology sharing and joint projects.

(2) Consider international practices

Drawing upon international experiences with carbon geological storage regulation provides a strong foundation for developing an effective and tailored framework for China's unique conditions. By studying well-established regulatory models such as the EU CCS Directive, the US Class VI regulations, and the ISO standards, as well as other materials such as the IOGCC model statutes, Chinese practitioners can identify best practices and establish a robust and adaptive regulatory system.

It is encouraging that China's standard authority is translating ISO 27914 and ISO 27916 into the national context and has publicly released draft versions for comment in January and February 2025. These drafts have retained almost all key components from the international versions, ensuring alignment with global best practices while adapting to China's specific needs.

However, integrating these standards is only a first step toward developing a comprehensive environmental regulatory framework for CO_2 geological storage in China. Table 6 has been developed based on the international best practices. A more comprehensive table, which demonstrates regulatory issues across a full project cycle, can be found in Appendix 1.

Table 6 - Proposed key considerations for environment-related regulations for China's CO_2 geological storage activities (Compiled by author)

PROJECT STAGE	KEY TECHNICAL CONSIDERATION	REGULATORY APPROACH
Pre-injection	• CO_2 stream characterisation • Site selection and characterisation • Storage unit requirements or reservoir suitability • Leakage pathway assessment and resolution where necessary	• Permitting & approval
Operations	• Injection well construction, completion and operation • Monitoring well construction, completion and operation • Modelling & Monitoring of Plume • Pressure monitoring and maintenance	• Monitoring, inspections, verification • Reporting • Enforcement (Fines, permit suspension, and legal proceedings)
Site closure & post-closure	• Post-Injection site care • Injection well plugging • Requirements for closure, including demonstration of secure storage	• Monitoring, inspections, verification • Reporting • Certification • Enforcement (Fines, permit suspension, and legal proceedings)
Cross-cutting	• Area of review • Demonstration/verification of secure storage • Testing and monitoring plans • Emergency response Plans • Financial assurance • Public outreach	

4.3 Recommendations for specific areas

China's existing environmental legal and regulatory frameworks provide a foundational starting point for regulating CO_2 geological storage activities. However, further regulatory development is needed to address areas where gaps remain. This effort should consider the unique characteristics and technical requirements of geological storage, such as CO_2 stream characterisation, site selection and characterisation, long-term testing and monitoring, emergency response planning, seismicity management, and post-injection site care.

(1) CO_2 stream characterisation

The 2016 Technical Guidelines on EIA for CCUS briefly acknowledge that "CO_2 streams containing impurities will exacerbate environmental risks," but they do not establish mandatory requirements. This gap increases the risk of corrosion in pipelines and injection wells, as well as potential adverse interactions between impurities and the storage reservoir. At present, the characterisation and monitoring of CO_2 stream composition are not consistently enforced across projects, resulting in variability in the quality of injected CO_2 and heightened risks to storage integrity.

Recommendation:

Develop and enforce national standards that define acceptable CO_2 streams to prohibit unnecessary additions of constituents and limit adverse impacts on containment. Align these standards with international frameworks such as the EU Directive 2009/31/EC, the US EPA's Class VI regulations, and ISO27921:2020.

(2) Site selection and characterisation

A regulatory gap in China for CCUS is the absence of a standardised system and procedure for site selection and characterisation. Key elements, such as the AoR, fault and fracture analysis, and metrics for evaluating reservoir suitability, remain undefined. Current site characterisation practices often lack detailed fault and fracture analyses, which are essential for identifying potential leakage pathways, while the absence of uniform requirements for fault mapping increases the risk of undetected subsurface vulnerabilities.

Additionally, advanced modelling techniques for delineating the AOR — a critical step in evaluating the potential impact of CO_2 migration — are not universally adopted, limiting the ability to accurately predict CO_2 plume behaviour and pressure changes over time.

Recommendation:

- Accelerating the localisation of ISO-related CCUS standards, including ISO 27914, ISO 27916, as well as ISO 2798:2018 (Lifecycle Risk Management for Integrated CCS Projects) and ISO TR27923:2022 (Carbon Dioxide Capture, Transportation, and Geological Storage – Injection Operations, Infrastructure, and Monitoring), among others, and updating when the ISO standards are updated.
- Develop a guideline for site selection and characterisation for CO_2 geological projects by the regulatory authority which can draw experiences on "the US EPA UIC Program Class VI Well Site Characterization Guidance."
- Introduce requirements for comprehensive fault and fracture mapping to improve leakage pathway assessments and enhance reservoir security, including avoiding harmful levels of induced seismicity.
- Standardise the use of advanced computational tools for AoR modelling to improve the accuracy of CO_2 plume behaviour predictions and risk assessments.
- Provide requirements for locating and evaluating any artificial penetrations within an AoR and taking corrective actions as necessary to avoid having them serve as leakage pathways.

(3) Testing and monitoring plans

Under the current Environmental Impact Assessment (EIA) requirements, projects in production or operation must conduct a post-evaluation of environmental impacts every 3-5 years and submit the results to the ecological and environmental supervision authority.[23] Additionally, oil and gas project developers are required to develop self-monitoring plans specifying factors, areas, frequency, sampling, analysis methods, and processes. However, there are no established monitoring requirements specific to CO_2 injection activities.[24]

The absence of official guidelines has resulted in significant variability in monitoring practices, with projects relying on their own judgment. For example, traditional environmental monitoring methods, such as soil gas and surface air measurements, have been implemented in the Shenhua and Jilin projects. Regulatory mandates are lacking for critical components, such as carbon stream analysis, CO_2 plume tracking, pressure-front monitoring, and the adoption of standardised techniques. This regulatory gap leads to inconsistencies in monitoring frequency, methodologies, and, ultimately, the quality and reliability of data.

Recommendation:

- Develop protocols for baseline, operational, and post-injection monitoring to ensure consistency and reliability across projects.
- Develop consistent requirements for siting, construction, operation, and closure of monitoring wells, including compatibility of materials and risk-based placement considerations that avoid inadvertently adding leakage pathways.
- Provide recommendations for site-specific assessments of monitoring techniques, such as soil gas surveys, satellite imaging, and fibre optic sensing, to detect near-surface CO_2 migration effectively, and encourage the adoption of real-time monitoring systems and machine learning algorithms to analyse monitoring data and identify anomalies promptly.
- Support research and development of innovative monitoring tools, such as autonomous drones and geophysical imaging, to enhance data collection capabilities.
- Good references for further reading include NETL (2018) Best Practices: Monitoring, Verification, and Accounting for Geologic Storage Projects and Hovorka et al. (2014) Workbook for Developing a Monitoring Plan to Ensure Storage Permanence in a Geologic Storage Project, which also covers site-specific tool selection for monitoring and verification.

(4) Emergency response, seismicity management, and post-injection care

Currently, MEE requires oil and gas developers to prepare contingency plans for environmental emergencies and submit them to local environmental authorities for record-keeping.[25] During the decommissioning of engineering facilities, developers or operators are required to implement effective ecological and environmental protection measures in compliance with relevant regulations. Similar regulatory requirements exist for certain other engineering projects; however, these are generally broad and lack a specific framework or detailed guidelines for post-injection monitoring and care. For example, Shenhua, now part of China National Energy Investment Corporation, has undertaken post-injection monitoring on a voluntary basis rather than as a regulatory mandate.

Recommendation:

- Establish a national framework for emergency response planning with clear guidelines for risk assessment, stakeholder engagement, and response execution to ensure a unified approach across projects.
- Develop a national guideline for managing induced seismicity risk, drawing insights from the Potential Induced Seismicity Guide: A Resource of Technical and Regulatory Considerations Associated with Fluid Injection (2021) by the Ground Water Protection Council and the Interstate Oil and Gas Compact Commission as well as the Interstate Oil and Gas Compact Commission model statutes and guidance on induced seismicity.
- Implement regular drills and training programs to enhance preparedness and coordination among operators, regulators, and local communities.
- Set minimum durations and detailed requirements for post-injection monitoring to guarantee long-term CO_2 containment and environmental protection.

5.0 CONCLUSION

China has made significant progress in CCUS project development in the past five years, which has greatly advanced the country's knowledge and technical capabilities. However, scaling up CCUS deployment at the national level requires the establishment of an effective environmental regulatory framework designed to address the unique challenges of CO_2 geological storage.

While existing laws and regulations in China address high-level principles of environmental integrity for general construction projects, critical gaps remain in areas specifically related to CO_2 storage, including the standardisation of practices, comprehensive monitoring systems, and long-term care provisions.

To address these challenges, China should prioritise developing mandatory standards and procedures for key aspects of CCUS projects. Learning from international experiences and engaging with global experts can provide valuable insights into regulatory design, accelerate mutual understanding, and promote best practices.

[23] 关于进一步加强石油天然气行业环境影响评价管理的通知, https://www.gov.cn/zhengce/zhengceku/2019-12/20/content_5462708.htm
[24] 环境影响评价技术导则陆地石油天然气开发建设项目, https://www.mee.gov.cn/ywgz/fgbz/bz/bzwb/other/pjjsdz/202308/W020230823384966732141.pdf

[25] Ibid

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7.0 APPENDIX 1

Regulatory issues and project operator regulatory obligations[26]

PROJECT STAGE	REGULATORY ISSUES AND OBLIGATIONS
Pre-injection	• Classification of CO_2 stream substances approved for disposal.
	• CO_2 stream characterisation.
	• Obtain authorisation to understand separation of designated areas for potential CO_2 storage, and compliance with relevant registration authority.
	• Ensure storage areas have very likely and most likely potential leakage pathways.
	• Activities may include seismicity testing or well-logging programs.
	• Determine CO_2 injection volumn for forecasting purposes
	• Use safe well construction and completion to ensure safe CO_2 containment.
	• Obtain all regulatory approvals including environmental impact reviews, land use change, modifications or infrastructure.
	• Conduct and gain authorisation for transfer agreements of capture, transportation and storage project.
	• Clarify transfer under CO_2 storage obligations.
Operation	• Capture CO_2 pursue relevant regulatory, restrictions, pollution prevention and control, health and safety, monitoring and reporting.
	• Maintain and ensure personnel with specific qualifications in injection area.
	• Ensure safe transportation of CO_2 to wells and injection, follow procedures and applicable law.
	• Ensure safety and security for perimeter of storage per injection authority.
	• Monitor injected substances and well performance.
	• Collect and report all monitoring, testing, recording.
	• Implement emergency and remediation response plan.
	• Immediately report damage or potential to environment, health, property.
	• Take corrective actions to address people and stakeholders.
	• Maintain financial security and insurance.
Closure	• Follow approved procedures specified within provision authority.
	• Obtain closure authorisation by regulatory authority, decommissioning all injection facilities and/or rehabilitation.
	• Remove or include removal of injection facilities and/or rehabilitation.
	• Continue to monitor wells and site performance.
	• Determine closure factor to apply for regulatory review.
Post-closure	• Long-term monitoring and site care.
	• Conduct corrective measures as needed per regulatory requirements.
	• Ensure site transition to storage authority.
	• Ensure operators fulfill, satisfy, or comply with all storage obligations under storage authority.
	• Transfer of liability where applicable.

[26] https://www.globalccsinstitute.com/wp-content/uploads/2025/03/Permitting-Lifecycle-FS_20250317.pdf

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