Project3： Studies of Environmental Impact and Risk Management of CO_2 Storage

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Center for Hydrogeology and Environmental Geology, CGS

Institute of Rock and Soil Mechanics, CAS

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2011.12

一、Activity targets and tasks

1. Activity targets

The project is intended to analyze the environmental impact and risk of CO_2 Storage, and summarize the international management measures about CCS, and recommend the monitoring technologies and methods, and provide policy recommendations for environmental impact assessment and risk management of CO2 storage.

2. Tasks

Task 1: Study on potential environmental impact and risk of CO2 storage

Task 2: Review of the management measures for environmental impact and risks of CO2 storage outside China

Task 3: Study on monitoring technologies and methods of CO2 geological storage

Task 4: Develop environmental management framework of CO2 storage for China

二、Partners

Chinese Academy of Environmental Planning, MEP
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The progress of the Project

一、Project Progress Summary

The project finishes the tasks based on the budget and on the schedule.

二、The progress and main conclusion

(1) Both the domestic and overseas researches on environmental impacts and risk during CO2 geological storage are summarized; the measures for environmental management of CCS technology in the developed countries are sorted out, which provide strong supporting basis for China to strengthen CCS environmental regulatory.

(2) New numerical simulation method is put forward and improved, the influence of abandoned well on leakage of CO2 geological storage is studied in view of the storage site with existing abandoned well; variation of leakage amount with time is also analyzed quantitatively, the influences of relevant factors on leakage is preliminarily analyzed, which provide technical and data supports for researches on CO2 geological storage.

Task 1: Study on potential environmental impact and risk of $CO2$ storage

In the view of both domestic and overseas research, we summarized environmental impacts and risks during CO2 geological storage indicated as Table 1. For site closure and post closure, the relevant risks are mainly discussed, which are presented as impacts from CO2 leakage.

Table 1 The environmental impact and risks of CO2 storage

Environmental indicators	Injection	Site closure and post site-closure
The use of raw material and water	The use of engineering material	
Plants and landscape		
Energy requirement	Inject for energy requirement	Monitoring for energy requirement
Waste product		
Air emissions	CO2 and CH4 leakage	CO_2 leakage
Social and economic impact	The adverse impact on agriculture and tourism	
Noise\light	No	
Soil contamination		Mobilization of metals and other contaminants
Soil disruption		Soil rise
Human health		
Ground/surface water		
Subsurface ecosystems		

Meanwhile, the current assessment institutions, assessment methods, assessment indicator and assessment tools of major countries in world are summarized too.

Based on the reviewing of some literatures, we conclude that the impact of CO2 concentration on ecosystems and organisms, as shown in Table 2.

Table 2 The effects of CO2 concentration

	No adverse effects	Adverse effects	Lethal/severe effects
Groundwater	< 0.2 % CO_2 is in general a normal concentration in groundwater	0.2 - 2 % CO_2: Elevated low acidity without significant impacts. > 2 % CO_2: Mild acidity and corrosion	> 6 % CO_2: Acidity, well corrosion, and irrigation loss
Freshwater ecosystems	The impact of a CO_2 leakage into a body of water will depend on the amount and rate of release, the buffering capacity of the water body, and its mixing dynamics.		

Fish	<1%	1-6 % CO_2: Fish has been observed to show signs of significant stress	> 2 % CO_2 concentration in water can be lethal to fish
Terrestrial ecosystems			A standard amount of CO_2 used to preserve food from insects, microbes, and fungi, is 40%
Invertebrates			
Mammals	< 1 % (estimated on the basis that most mammals react similar to human beings when exposed to CO_2). Hibernating mammals have higher tolerance levels.		
Plants	Slightly raised (500–800 ppm) levels of CO_2 usually have the effect of stimulating growth in C3 plants, whereas the response in C4 and CAM plants is less obvious. In the long term, ecosystem changes in favour of the C3 plants may be expected. There seems to be little benefit in CO_2 concentrations above 800 ppm, but plants can be expected to tolerate concentrations of 1000 ppm (1 %) comfortably. Plants are fairly tolerant to short-term exposure.	> 5 % CO_2: Deleterious effects on plant health and yield. 5 to 30% CO_2: Severe effects to be expected in this range.	>20% CO2 in soil gas: Long term exposure (weeks or months) has been observed to lead to dead zones where no macroscopic flora has survived > 30 % CO_2 in soil gas is defines as a lethal concentration level for plants .
Microbes and fungi	Short-term exposure	5 – 60 % CO_2: growth	50 % CO_2 has in

	would require quite high concentrations of CO_2 to be harmful for microbes and fungi. For mycorrhizal fungi, species composition effects from long-term exposure could occur even from a limited increase in CO_2 concentration in the atmosphere.	of fungi mycelium decreases linearly with increasing CO_2 concentration. A standard amount of 40% CO_2 is used as a standard to preserve food from insects, microbes, and fungi. At this amount, insects are incapacitated or killed and microbes and fungi either die or experience severely retarded growth rates	general a significant inhibitory, if not lethal, effect on microbes and bacteria
Deep subsurface ecosystems	Not enough information about subsurface ecosystems, such as the distribution and physiology of microbes in the subsurface, is known to make a reliable estimation of concentration limit values.		
Human health	< 1 % CO_2 Swedish occupational safety regulations: Hygienic threshold value for exposure during a working day: 0.5 % Short time threshold value (average exposure during 15 minutes): 1 %	1 - 3 % CO_2: Increased breathing, headache and sweating. Physiological adaptation occurs without adverse consequences. 3 - 5 % CO_2: Significant effect on respiratory rate, increased blood pressure and some discomfort > 5 %, physical and	> 10 % CO_2: Severe symptoms, including rapid loss of consciousness, possible coma or death, result from prolonged exposure > 25-30 % CO_2: Loss of consciousness occurs within several breaths and death is imminent

		mental ability is impaired and loss of consciousness can occur.	

（2）For the storage site with the existing abandoned well, the influence of the abandoned well on CO_2 geological storage was researched through numerical simulation method. It was showed from the research that CO_2 leakage varied with time. The timing point when the storage well begins leakage is 10 days after CO_2 was injected; after that, the leakage rate will quickly increase, and reach to the peak value in 42 days after CO_2 injection. Its max leakage rate is 0.221% of CO_2 injection rate; and then the leakage rate will gradually lower and tend to be smooth with time goes on, which is mainly determined by the finite area of model. In the actual infinite formation, CO_2 leakage rate will rapidly reach to max value and tend to be smooth with a little increase, instead of lowering.

The above results provide reference basis for recommendation of EIA (environmental impact assessment) element matrix, concentration range of CO_2 leakage risk, and assessment methods which are used for EIA of CO_2 geological storage.

Task 2: Review of the management measures for environmental impact and risks of CO2 storage outside China

The relevant laws and regulations have been formulated for CCS technology in Australia, European Union, Japan and UK, which mainly provide the detail provisions covering storage permit, EIA, site conditions and monitoring, etc. it could provide good reference for China to formulate the relevant regulations in future.

3.1 Environmental Guidelines for Carbon Dioxide Capture and Geological Storage – 2009

This guideline requires CCS projects will be subject to the following principles which underpin the resource management and environmental protection regulatory framework that has been endorsed over time by the Council of Australian Governments. And it provides guidance to environmental assessment, monitoring and site closure of CCS projects, and coordination of environmental regulation by jurisdictions.

(1)Environmental Assessment:

All CCS projects will be subject to environmental assessment and approval in the relevant jurisdiction under the appropriate legislative regime. Groundwater resources must be included in all risk assessments to protect regional water resources.

(2)Monitoring

Appropriate monitoring will be an essential element in the conditions of approvals for all CCS projects. Monitoring will be required for site safety, environment protection, public health and resource management.

(3)Site Closure:

Proponents will be liable for all aspects of a CCS project during the life of the project and be required to meet agreed performance standards for closure, including meeting the cost of post closure monitoring.

3.2 DIRECTIVE 2009/31/EC OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 23 April 2009 on the geological storage of carbon dioxide and amending Council Directive

This Directive establishes a legal framework for the environmentally safe geological storage of carbon dioxide (CO_2) to contribute to the fight against climate change. And it provides guidance for selection of storage site, storage permit, risk assessment, monitoring and so on.

The risk assessment shall comprise hazard characterization, exposure assessment, effects assessment and risk characterization.

The monitoring plan shall provide details of the monitoring to be deployed at the main stages of the project, including baseline, operational and post-closure monitoring.

3.3 Marine Pollution Prevention Law in Japan

In 2007, Japan amended Marine Pollution Prevention Law about CCS technology. It requires that: (1) Prohibition of disposal of oil, hazardous liquid substances and waster under the seabed, except for CO_2 stream storage under the seabed with permit from Minister of the Environment; (2) Provisions for the permits for CO_2 stream storage under the sea bed; (3) Designation of a registered area in order to prevent potential impact on marine environment from CO_2 leakage by altering the seabed and the sub-seabed features; (4) Application for a permit including a project plan, monitoring plan and environmental impact assessment report. Monitoring plan should include monitoring under normal situation, for possible CO_2 leakage, for adverse impact in case of leakage. Environmental impact assessment report includes characterization of CO_2 stream; location, spatial extent, and amount of potential CO_2 leakage; baseline data of marine environment at the storage site; and evaluation of impact by potential CO_2 leakage.

3.4 The Storage of Carbon Dioxide (Licensing) Regulations 2010 in UK

This regulation will come in force on 6th April, 2010. It requires that when applying for a storage permit, it should include a proposed monitoring plan, and proposed corrective measures plan, and a proposed provisional post-closure plan. And one of the satisfied conditions for granting a storage permit is there is no significant risk of leakage or of harm to the environment or human health.

3.5 The environmental impact assessment of Barendrecht project

We review the total environmental impact assessment report of Barendrecht project, and conclude the environmental impact matric and assess method.

Task 3: Study on monitoring technologies and methods of CO_2 geological storage

Based on the systematical data collection and analysis on both domestic and overseas monitoring technologies of CO_2 geological storage in deep salt aquifer, a suitable “atmosphere-surface-well” monitoring system is preliminarily established in combination with the actual situations (see Fig. 1). The monitoring technologies are shown as Table 3.

Fig.1 Monitoring system of CO2 storage

Table 3 Schedule of monitoring technologies & methods for CO2 geological storage

Designation	**Monitoring targets and objects**	**Outcome**	**Criteria for environmental impact and safety**
Monitoring CO_2 leakage temperature and vegetation spectral features	Vegetation conditions and air heat conduction in the CO_2 storage site	Infrared image data and vegetation spectral features	Monitor CO_2 leakage through obtaining infrared image data of the specified spectral coverage; identify vegetation anomalies to judge CO_2 leakage spots by means of spectral difference;
Atmosphere monitoring	CO_2 concentration variation in the CO_2 storage site	1. CO_2 storage site in atmosphere; 2. Temperature, humidity, wind speed, wind direction and atmospheric stability; 3. Percentage of ^{13}C stable isotope in atmosphere	Judge whether there is any leakage in the CO_2 storage site through analysis on variation of CO_2 storage site in atmosphere
Monitoring surface deformation	Deformation of terrain and crust in the CO_2 storage site	Surface deformation	Judge whether CO_2 storage has caused surface deformation or not, and then whether there is any CO_2 leakage

Monitoring gas in soil	Variation of CO_2 concentration in soil before and after the CO_2 storage site	1. CO_2 flux in soil air, CO_2 concentration in soil air; 2. Percentage of ^{13}C stable isotope in soil air; 3. Temperature and humidity.	Subtract effect of natural factors on CO_2 concentration in soil air, and then analyze and judge whether there is CO_2 leaked into soil through comparison with CO_2 concentration variation before and after injection.
Monitoring groundwater quality	Significant change of groundwater quality before and after the CO_2 injection	Water temperature, pH value, conductivity, total dissolved solids (TDS) HCO_3^-, Ca^{2+}, Mg^{2+}, Cl^-, Pb, As and ^{13}C stable isotope, etc.	Variation of groundwater quality at monitoring spot before and after CO_2 injection could be taken as important basis to judge whether there is CO_2 leaked into groundwater
Monitoring the monitor well	Information on internal formation at the CO_2 storage site	Formation pressure, temperature and pH value	The collected information on formation could be provided as basis to judge influence of CO_2 storage on the formation; the information on CO_2 underground migration could be obtained through the collected information on water sample
Time-lapse seismic monitoring for CO_2 underground migration on the basis of subsurface structure	Subsurface structure of CO_2 storage site, and conditions of CO_2 underground migration	Thickness of reservoir and cap rock, spatial distribution range, physical parameters of reservoir and cap rock, conditions of CO_2 underground migration after injection	Provide relative accurate information on stratum structure for CO_2 storage, detect and analyze CO_2 underground migration, diffusion and shifting after injection, provide basis for operation and management of CO_2 storage site

Task 4: Develop environmental management framework of CO2 storage for China

At present, China has carried out some demonstration projects of CO_2 geological storage, it is urgent to strengthen environmental regulations and reference the relevant experiences of the developed countries. It is suggested that:

(1) From the perspective of laws, the regulations shall be definitely provided for permit of CO_2 storage project, which include the environmental elements of site selection, EIA through whole life cycle of the project, monitoring procedure and plan, injection CO_2 purity, transferring responsibility of environmental regulatory before

and after site closure, early warning for environmental risk and emergency response, investigation of leakage liability and compensation mechanism.

(2) From the perspective of EIA, we suggest that it will be better to assessment environmental risk for CO_2 geological storage, define environmental impact and risks of CO_2 geological storage, recommend EIA environmental element matrix, formulate assessment rating and relevant assessment criteria, and recommend minimum acceptable risk levels for different ecological system.

(3) From the perspective of environmental monitoring, it is suggested that the monitor plan and scheme shall be prepared as mandatory requirement in form of law; it is required that background monitoring shall be conducted before and after the project was implemented; in addition, the technical specification for monitoring shall be formulated to define the regulatory responsibilities of the government/the third party.

(4) From the perspective of license and application, it is required that the project operator must submit the approved EIA report, monitoring plan, and scheme of remedial measures on the basis of conditions for site selection satisfied, so as to ensure environmental safety of CO_2 storage project.