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Technology Demonstration, Knowledge Sharing and Non-technical Support for Implementation toward Commercial Deployment of Geological CO_2 Storage

1. Introduction

With the successful projects of CO_2 capture and storage (CCS) from natural gas processing, Sleipner and Snøhvit in Norway, CCS has been considered a key feasible measure to mitigate global warming. Recently, large-scale CCS projects have been planned and commenced in the United States, Canada and Australia.

Japan has successfully completed a 10,000 ton CO_2 injected pilot project in Nagaoka, Niigata, followed by a 300,000 ton CO_2 injected demonstration project in Tomakomai, Hokkaido.

Commercial deployment of large-scale CO_2 geological storage requires safe injection and storage of more than 1 Mt/y. The CO_2 Storage Research Group as a member of the Geological Carbon Dioxide Storage Technology Research Association has conducted a project funded by the New Energy and Industrial Technology Development Organization (NEDO), called "Research and Development of CO_2 Storage Technology to implement safe CCS". The project has been addressing the development of technologies for safety management, efficient injection and effective resource utilization for large-scale CO_2 reservoirs, including the non-technical support for facilitating social implementation and deployment of CCS. Our outstanding outcomes up to now are the safety management system for injection; the optical fiber measurement technology for strain, acoustic and temperature; the microbubble CO_2 injection technology.

Based on these outcomes, the CO_2 Storage Research Group has moved forward in 2021 toward commercial deployment of CCS by technology demonstration, improvement of economics, risk mitigation, and facilitation of implementation. Regarding the technology demonstration, we have been applying and verifying our optical fiber measurement technology at large-scale storage sites overseas. For the improvement of economics and risk mitigation, we have been developing a new measure to enable a comprehensive investigation of the storage opportunity in Japan, which is called CO_2 Storage Resource Management, SRM.

The CO_2 Research Group has been compiling the Practical Guidance for Geological CO_2 Storage as reference manual for CCS developers. It will be available for developers and usable for their overseas deployment of CCS. Furthermore, our group has been developing frameworks for creation of social consensus (Social License to Operate, SLO) by advancing conventional Public Acceptance (PA) and Public Outreach (PO) approaches. We have a plan to apply and demonstrate our SLO methodology for domestic CCS deployment at a full scale.

The CO_2 Research Group continues to contribute to CCS deployment not only by technical demonstrations for commercial deployment but also by sharing our knowledge and facilitating the social implementation of CCS.

2. Major Research Topics and Outcomes

2.1. Optical fiber measurement technology development and demonstration

For ensuring safe CO_2 geological storage, it is essential to monitor the location of injected CO_2 plume, the deformation of geological formation induced by pressure rises, and the area of pressure propagation.

One of the suitable technologies to enable these monitoring is the Distributed Fiber Optical Sensing (DFOS). DFOS technology is capable of acquiring spatially continuous data because the optical fiber itself is the sensing receiver. This feature of the DFOS enables monitoring of the deep direction continuous data when installing the optical fiber cable along the wellbore. Moreover, the DFOS can work as a multi-sensor system to capture temperatures, strains and acoustics simultaneously by installing multiple optical fibers together. The system is potentially much cheaper than a case where many sensors are installed.

The CO_2 Storage Research Group has been developing the technology of the optical fiber measurement and demonstrating it in the field in Japan and overseas as below.

Two conventional designs of optical fiber cable have been used for optical fiber measurements. One is the Telephone line type, which consists of multiple optical fibers covered by soft resin, and the other is the Armored type, which outer jacket made of twisted wires. We have designed a noble optical fiber cable for better installation and sensitivity that contains multiple fibers filled with resin in a stemless tube, called the SUS tube type.

The performance of the new cable was tested and compared to the other two conventional cable types by the Water Injection test in a domestic site. The test was conducted by installing three cables of a different type to a well while injecting water to another well nearby. Fig.1 shows the test result. The new cable is more sensitive than the other conventional cables to monitor the minute geological strain caused by injecting water.

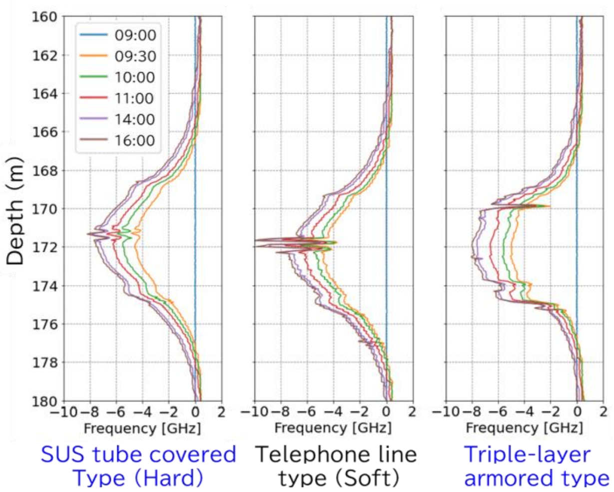

Fig. 1 Strain of Geological Formation by Water Injection Test for different types of optical fiber cable

The demonstration of our DFOS has been conducted at three overseas sites for different purposes through 2023.

We will monitor the behavior of injected CO_2 in addition to the stability of formation and the integrity of well by applying the DFOS at the large-scale CO_2 injection site in North Dakota, USA. We have installed the optical fiber cable to the wellbore, enabling us to monitor CO_2 injection. By demonstrating our DFOS at the large-scale site, we will complete the development of measurement technologies: multiple sensing, Distributed Acoustic Sensing (DAS) and Vertical Seismic Profiling (VSP).

At the site in Australia, a demonstration test using our DFOS for monitoring formation stability has been conducted. We will monitor CO_2 migration along shallow faults and deep formation stability by installing the optical fiber cable in the well near the faults.

We have been demonstrating our DFOS to monitor deformation of seabed surface by installing the optical fiber cables in a shallow seashore of German offshore by joining the international cooperation project and sharing information with several research partners including the Norwegian Geotechnical Institute (NGI).

2.2. Development of Storage Resource Management (SRM) System

The Storage Resource Management System (SRM) is a measure of the improvements in storability and economics of CCS. Two main subjects are;

- Accomplish an effective utilization method of geological storage capacity (resource) for large-scale CO_2 reservoirs.
- Develop an economic assessment tool to estimate overall CCS business costs including risk costs associated with operations.

Fig. 2 shows the scope of the SRM system in terms of a CCS business covering the entire CCS value chain from capture, transport and storage. This includes a time sequence from a screening of regional potential to long-term management after the closure of CO_2 storage sites. The economic assessment tool will be developed to estimate overall CCS business costs including risk costs associated with operations.

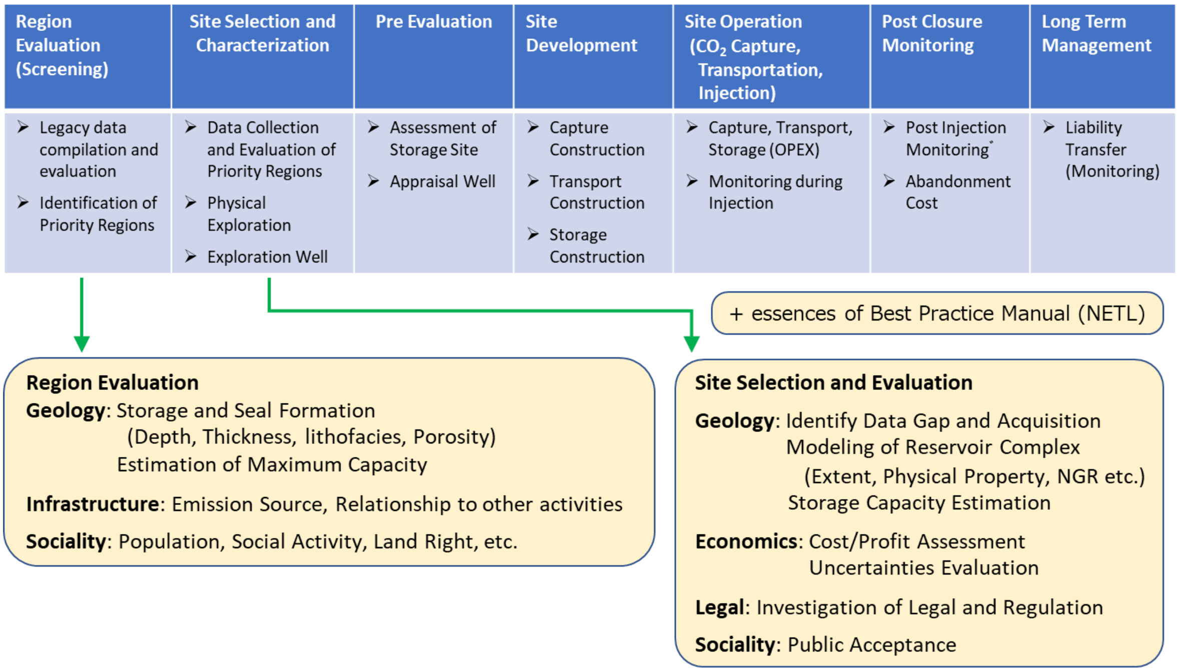

Fig. 2 Scope of SRM system in CCS business

Both the proper selection of CO_2 storage sites and the effective utilization of reservoirs are pivotal factors in the economic assessment. Our group has been addressing the following technical developments;

- Geological modeling for large scale reservoir.
- Techniques of optimizing a layout of CO_2 injection wells and pressure management wells.
- Methodology of CO_2 behavior simulation and long-term prediction.

The measure to evaluate and manage storage resources will be built by expanding these technical elements.

For the establishment of the effective utilization of reservoirs, we refer to the international standard, ISO 27914: 2017 Carbon dioxide capture, transportation and geological storage - Geological storage and CO_2 Storage Resources Management System (SRMS) by Society of Petroleum Engineers (SPE, 2017). ISO 27914 defines the requirements and recommendations to facilitate safe and long-term sequestration of CO_2 in deploying commercial CCS that minimize the risks to the environments, natural resources and human health. SPE SRMS provides classification framework for accounting the storage capacity of CO_2 from “undiscovered” to “commercial”. While it provides generic guidelines, uncertainties in geological evaluation and technical risks associated with selected sites must be handled based on each CCS business project.

It is crucial to consider the origin of geological formation in order to estimate uncertainties in geological evaluation. RITE’s CO_2 geological storage potential survey (Fig. 3) is the existing geological information that concludes the estimation of CO_2 storage quantity utilizing base data of oil and gas resource exploration conducted (RITE, 2006). It was derived from the distribution of deep saline aquifers at depths below 800 m where CO_2 is in a supercritical state. Deep saline aquifers are consisted of alternation of sand and mud. Due to uncertainties in homogeneity and continuity of geological formation, detailed investigation needs to be conducted. Advancing the investigation of uncertainties will update the storage resource data more precisely.

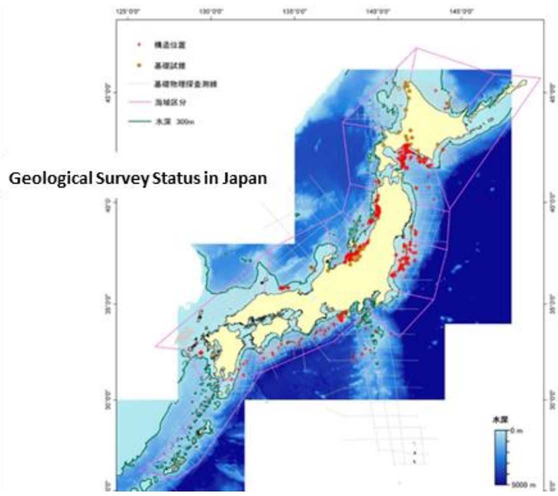

Fig. 3 Distribution map of anticline structure in Japan by base physical exploration survey.

The distance between a CO_2 storage site and an emission facility is a key factor in determining the mode and cost of CO_2 transportation, which impacts the economics of CCS business. Low cost and Low risk business models have been investigated by matching nearby emission sources with several assumed storage sites selected based on geological data and storage capacity estimation (Fig. 4). This business model investigation is aligned with the business development that will gradually expand as described in the METI report. However, there are data gaps in some regions for assuming storage sites and different kinds and volumes of emission sources (coal-fired power plant, iron and steel, chemical plant). By identifying several candidates for CCS business site, our group will share knowledge of geological survey in the regions and propose CCS business models that enable early deployment. In addition, the cost estimation tool for CCS business will be developed. All CCS value chains (capture, transport and storage) will be taken into account in the tool for calculating overall CCS business cost. It will contribute to the development of financing and insurance for CCS business.

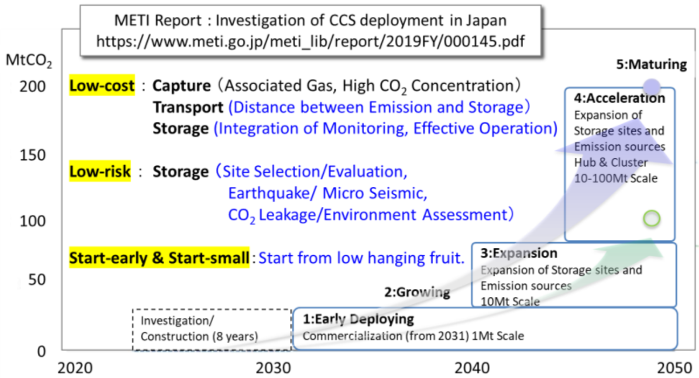

Fig. 4 Concept of the Early Realization CCS Business Model.

2.3. Creation of Social Consensus, Knowledge Sharing and Technical Support to Deploy CCS

The deployment of CCS at scale requires frameworks for CCS business, public understanding and social consensus as well as technology advancement and commercialization. To support CCS business, our research group has compiled guidance for developing an Incident Response Protocol for CCS developers and operators (Japan Specific IRP) and has been producing Practical Guidance for Geological CO_2 Storage. To enhance public understanding and create consensus in society, we have also been working on the development of frameworks for creation of social consensus (Social License to Operate, SLO).

2.3.1. Incident Response Protocol (Japan Specific IRP)

It is essential to have clear procedures and plans, *i.e.* protocols at hand, for the case where any incident occurs in order to secure security, to take appropriate emergency response in a geological CO_2 storage operation and also to retain public support. An incident is defined here as an event which has risks to delay or interrupt geological CO_2 storage development and operation. Potential incidents include abnormality in operation such as those in wells and CO_2 reservoir; events that can cause abnormality in operation such as intensified earthquakes, typhoons and identification of unknown faults; adverse impacts on subsurface and the external environment such as the deformation of formations and surface, CO_2 leakage and induced seismicity; and adverse impacts on the ecosystems, resources and assets such as changes in the ecosystems, CO_2 contamination in drinking water, damage to human lives, health and houses. (See Fig. 5)

We call incident response protocols for CCS developers and operators to conduct a geological CO_2 storage project in Japan as a Japan Specific IRP and have developed guidance for developing one.

For the Japan Specific IRP, we define three emergency levels in accordance with degree of impacts on the external environment. Level 1 is when there is no adverse effect derived from the emergency; Level 2 is when adverse effect may appear if the situation becomes worse; and Level 3 is when there is being adverse effect. When incident happens, the developer or operator judges an emergency level, forms a response team based on the level and then takes appropriate technical and social responses to the emergency. The technical responses include investigation and monitoring of the incident; remediation of portion where incident occurs; and mitigation, prevention and restoration of the effect. The social responses include correspondence with administrative organizations; and communications with local stakeholders, the general public and mass media. The guidance contains a number of examples for responses to each listed potential incident.

As a complement to the Japan Specific IRP, we have produced a Q&A book. The book covers answers based on scientific evidences to anticipated questions regarding to impacts of earthquakes on CO_2 reservoir, seismicity induced by CO_2 storage operation, effects of CO_2 leakage on human, living organism and the environment.

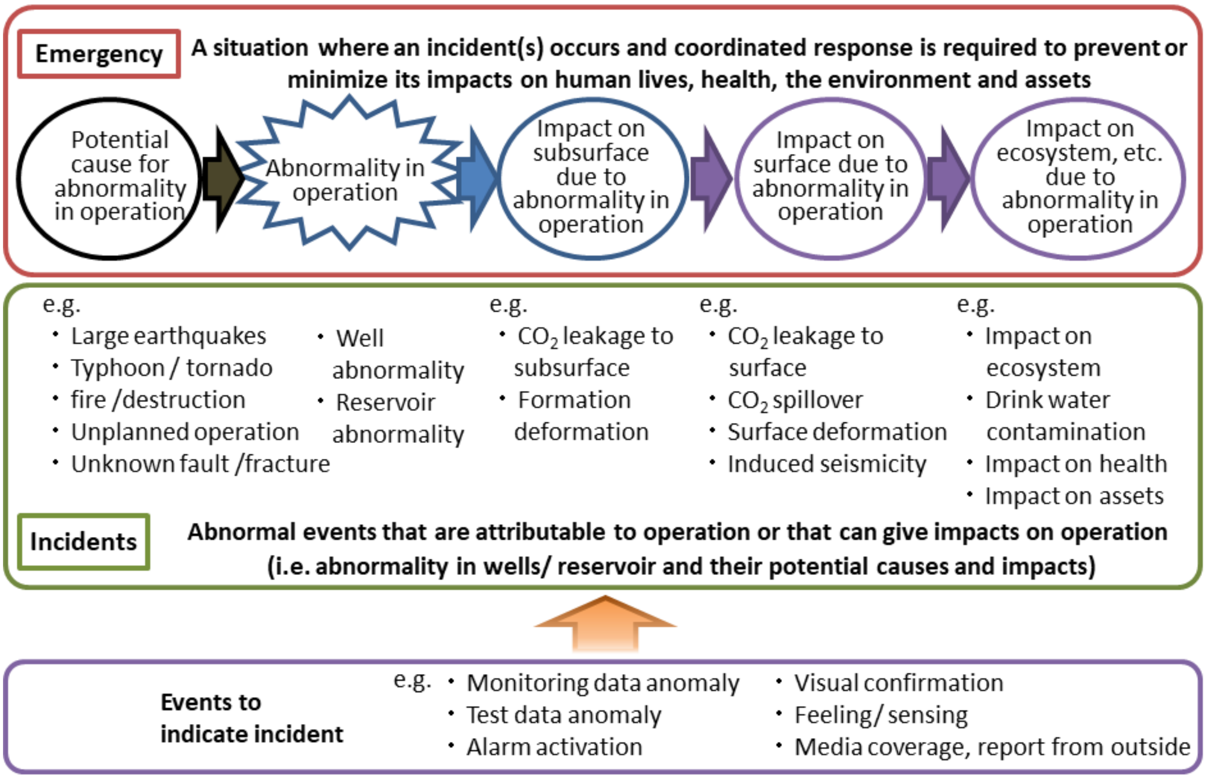

Fig. 5 Emergency Categories and Examples of Incidents

2.3.2. Practical Guidance for Geological CO_2 Storage

As a reference manual for developers and operators of CCS in Japan, our research group has been developing a Practical Guidance for Geological CO_2 Storage to summarize domestic and foreign case examples regarding to geological CO_2 storage.

The guidance consists of eight chapters based on the phases of geological CO_2 storage development and operation: Basic Plan; Site Selection; Site Characterization; Implementation Plan; Design and Construction; Operation and Management; Site Closure; and Post-closure Management. The Chapter 1 on Basic Plan was completed, available on our website in October 2021.

The aim of basic planning is to get understanding of a project from stakeholders by presenting its overview at a phase of project initiation. What to examine, plan and accomplish in the basic planning are diversified, ranging from technical aspects to economic, legal and social aspects. The Chapter 1 of the guidance shows all phases in the whole of project planning and outlines each of the phases.

The guidance summarizes relevant domestic and foreign legal and regulatory frameworks and clarifies timings of permission and authorization required. For economics, it presents an overview of project costs and breakdown costs of an oversea project. In addition, the document touches upon an overview of how to consider risk management and public outreach and public acceptance (PO/PA).

Chapter 2 to 8 describe each of the phases in detail, which will be published one by one. In order for them to be used overseas, their English versions are being compiled and will be publicly available.

2.3.3. Creation of Social Consensus for CCS Implementation (SLO)

Implementation of CCS in society needs social consensus. Our research group has therefore been developing methodology for the creation of social consensus (SLO).

What is essential in implementation of CCS is support from the local community. To get local support and consensus, it is critical to make well communications between local stakeholders and CCS developers/ operators. In overseas cases, it is recommended to start two-way communications at an early stage. The two-way communications is different from communications where a developer/ operator explains their project to the local unilaterally and requests them to accept it. It does mean that local people share their opinions, thoughts and concerns with the developer/ operator and as a result mutual understanding and mutual trust are built. There have been a number of proposed two-way communications methods. Our research group is examining how the developer/ operator should communicate with whom in the local community at each phase of a project. We are also analyzing economic ripple effects generated by the project to the local.

Consensus in society does not just mean simply that local people and general public accept CCS. In society there are diversified stakeholders from local residents and general public through investors and policymakers to the developer/operator. Different from many other non-CCS projects, CCS itself generates no profit so that consensus among investors, policymakers and the developer/ operator requires incentives as mechanisms to deliver business case. We are therefore examining incentives in other countries to design those suitable for Japan. We are also making analysis on costs of CCS projects. Through studies such as cost analysis for overseas projects, we are investigating breakdown of costs and their yearly changes.

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