CO_2 Storage Research Group

Member (As of Apr. 2023)

Ziqiu Xue, Group Leader, Chief Researcher
Nobuo Umeda, Deputy Group Leader, Chief Researcher
Satoru Yokoi, Chief Researcher
Makoto Nomura, Chief Researcher
Nobuo Takasu, Associate Chief Researcher
Takahiro Nakajima, Associate Chief Researcher
Takeshi Myoi, Associate Chief Researcher
Tsutomu Hashimoto, Associate Chief Researcher
Saeko Mito, Senior Researcher
Tetsuma Toshioka, Senior Researcher
Osamu Takano, Senior Researcher
Keisuke Uchimoto, Senior Researcher
Hironobu Komaki, Senior Researcher
Atsushi Ibusuki, Senior Researcher
Yuji Watanabe, Senior Researcher
Yi Zhang, Senior Researcher
Hyuck Park, Senior Researcher
Jiro Suekuni, Senior Researcher
Yuji Yamashita, Senior Researcher
Ken Asajima, Senior Researcher
Satoko Fuchikami, Vice Manager
Kimiko Nakanishi, Chief
Takayuki Miyoshi, Researcher
Masafumi Kotani, Researcher
Takeya Nagata, Researcher
Rasha Amer, Researcher
Jinrong Cao, Researcher
Ryota Okimoto, Researcher
Tomonari Minezaki, Researcher
Shoichiro Hozumi, Researcher
Junko Hirai, Research Assistant
Shiori Tsuji, Research Assistant
Yuko Himi, Research Assistant
Akemi Nishide, Research Assistant
Megumi Okumichi, Research Assistant
Megumi Sasaki, Research Assistant
Tokio Sasai, Research Assistant
Nae Hidaka, Research Assistant

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

1. Introduction

“CCS Long-Term Roadmap” which was compiled by the government in March 2023 says that CO2 geological storage-scale as of 2050 is 120-240 million tons. Aiming to start the CCS business in 2030, they are speeding up the development of the environment for practical use of CCS, including the legal system. At the same time as ensuring the safety of the CCS project, technology development for cost reduction, etc. is also required.

Technology development of CO2 geological storage technology in Japan started with a small-scale demonstration project (10,000 tons of CO2 injection) in the suburbs of Nagaoka City, Niigata Prefecture in the early 2000s, and various basic technologies were developed by the early 2010s. After that, a large-scale CO_2 injection demonstration project of a total of 300,000 tons was conducted at the off the coast of Tomakomai, Hokkaido.

CO_2 Storage Research Group is working on the practical application of CO_2 storage technology on the scale of 1 million tons per year (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 main purpose of this project is to develop technology to improve the safety and economic efficiency of the CCS project and to prepare the conditions for the wide adoption of CCS. We have developed Distributed Temperature Sensing (DTS), Distributed Strain Sensing (DSS) and Distributed Acoustic Sensing (DAS) measurement technologies, and microbubble CO2 injection technology to improve storage efficiency. Currently, we are proceeding with technical demonstration project at domestic and overseas sites. We are also working on the development of methods to improve the social acceptance of CCS technology toward social implementation.

Regarding optical fiber measurement technology, we are also accumulating know-how such as verification of effectiveness and measurement system operation for practical application to domestic CCS projects at large-scale CO_2 injection sites in the United States. About the matching of emission sources and storage sites and about the economic improvement (cost reduction) of domestic CCS projects", we are considering the " Storage Resource Management " (SRM) method based on existing geological information and underground exploration data. In addition to the conventional storage potential assessment, we are also developing a CCS cost estimation tool that enables optimal business planning by SRM. In addition, our group has been developing frameworks for creation of social consensus (Social License to Operate, SLO) which is useful for domestic CCS projects by advancing conventional Public Acceptance (PA) and Public Outreach (PO) approaches.

2. Major Research Topics and Outcomes

2.1. Optical fiber measurement technology development and demonstration

In geological carbon storages, it is required to confirm that the injected CO2 is stored subsurface safely. We need to monitor integrity of wells and CO2 pipelines to obtain deformation change due to the increase of formation pressure, area of pressure propagation and leakage detection. The Distributed Fiber Optic Sensing (DFOS) technology is highly prospected for this monitoring purpose.

The DFOS measures spatially continuous data along the optical fiber (OF) cables, as the OF cable itself works as sensors. A single OF cable with multiple fibers enclosed can be a multi-sensor system to obtain acoustic (Distributed Acoustic Sensing: DAS) temperature (Distributed Temperature Sensing: DTS) and strain (Distributed Strain Sensing: DSS), simultaneously. This system can reduce the cost significantly compared with the case which many sensors are installed separately.

Our research group has developed the monitoring system with the DFOS technology through the laboratory experiments and field measurements. Currently we demonstrate our monitoring systems at various sites in Japan and overseas. At the domestic site, we evaluate the sensitivities of the newly developed OF cable, and verify the effectiveness of the DFOS monitoring system under the practical environment such as the injection at multiple wells. At the CCS site in North Dakota (ND), USA, we demonstrate the integrated monitoring system with DAS, DTS and DSS using the developed OF cables.

The CCS project in ND, USA injects 180,000 tons of CO2 annually captured from the ethanol facility into the deep saline aquifer approximately 2,000 m below ground surface. The CO2 operation was started at mid of June, 2022 and over 100,000 tons of CO2 was stored at the end of March, 2023.

Our DFOS system is used for CO2 monitoring in this project. Fig. 1 shows the map of the ND CCS site and a schematic diagram of the monitoring system with the DFOS technology. Simultaneous measurement systems of DAS (acoustic), DTS (temperature) and DSS (strain) is implemented by installing the developed OF cables at four wells (an injection well, an observation well, two shallow groundwater observation wells) and the CO2 pipeline. Table 1 summarizes the monitoring targets of each measurement system.

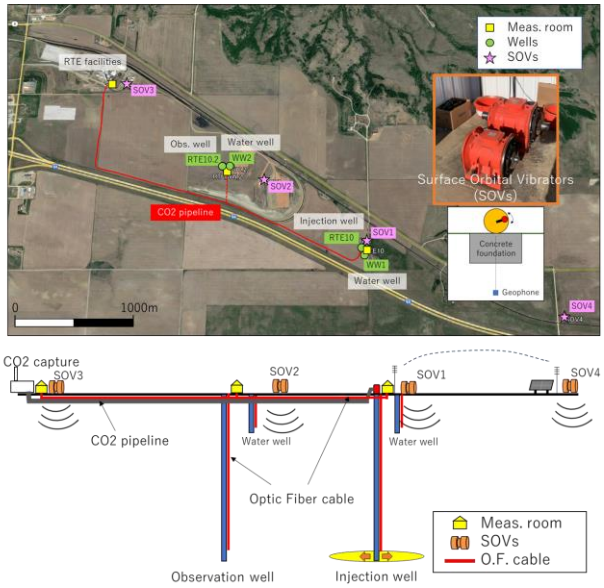

Fig. 1 Monitoring system with O.F. sensing

Table 1 Monitoring targets

DAS (Acoustic)	CO2 plume, induced/natural seisimicity
DTS (Temperature)	Well/pipeline integrity
DSS (Strain)	Geological stability of reservoir/cap rock

The borehole seismic with DAS (DAS-VSP) is used at two of deep wells to capture a CO2 plume subsurface. The VSP (Vertical Seismic Profiling) is one of the exploration seismic techniques and has advantages for high resolution and quality imaging due to the short distance between the target and receivers compared to the surface seismic. The OF cable works as the permanent seismic receivers installed behind the well pipe, which reduces the operation time and costs significantly especially for repeated surveys and also reduces the acquisition errors due to the gap of the receiver locations. The OF cable with small dimensions is installable behind the well pipe even at the injection well.

Repeated 3D seismic surveys are typically carried out every one to several years for the purpose of capturing the CO2 plume. In order to fill this temporal gap, we implemented surface orbital vibrators (SOVs), which can acquire data much more frequently. The SOVs are permanent vibration devices that transmit vibrations in the strata by rotating eccentric weights at high speed. In addition, there is no need for on-site operators for data acquisition, as remote operation and automatic controls are available. At the ND site, four SOVs are installed around the site and operated every day.

Fig. 2 shows DAS results excited by SOVs installed at the offset of about 60 m and about 1,000 m from the injection well, respectively. Direct P-waves continuing from the upper left to the lower right propagate from the surface to the underground (down-going), while waves continuing from the upper right to the lower left represent reflected waves propagating upward from the underground (up-going). Reflected P-waves, which are the main signals in VSP data processing, are well recorded with the good signal-to-noise ratio. The zero offset VSP recordings, which were obtained by the source sweepings at the closest SOVs, are used to detect the CO2 plume immediately after the start of injection, and other VSP recordings with certain offsets are used to capture the area of the CO2 plume. We are currently conducting time-lapse analysis of repeated VSP recordings.

Fig. 3 shows the DTS result at the injection well before and after the start of injection. The color contour chart clearly shows spatial and temporal temperature changes. While the temperature distribution along the well due to the geothermal gradient is consistent before the start of injection, the temperature drops by about 20 °C immediately after the start of injection. This represents that the low-temperature injected CO2 cools surrounding ground temperature. Moreover, even after the start of injection, repeated short-term temperature rises and drops are observed. This indicates the process in which cooled temperature tends to recover to the original formation temperature due to the temporary suspension of injection.

Spatially continuous DSS (strain) from the deep underground to the surface is performed to monitor the deformation of the strata caused by the CO2 injection. In the ND CCS project, we also monitor ground surface deformation using the satellite data in order to evaluate the relation between the ground surface deformation and CO2 injection at the deep strata.

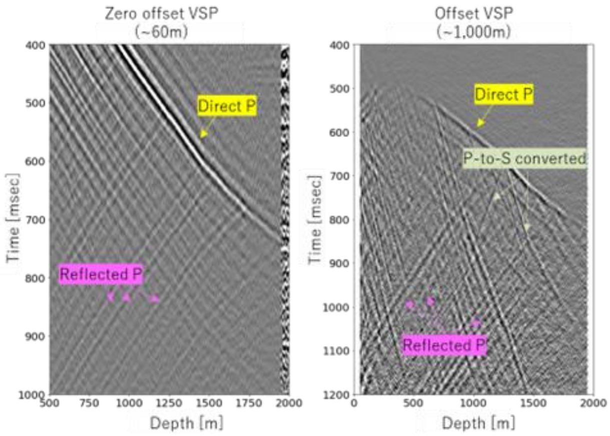

Fig. 2 SOV-DAS records

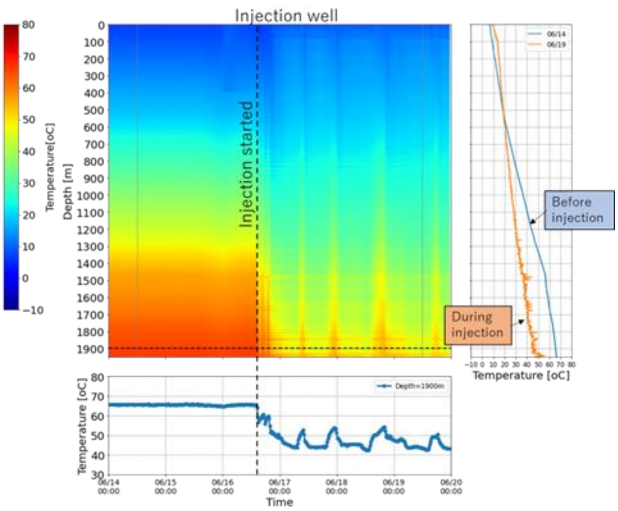

Fig. 3 DTS result before/after start of injection

On the other hand, at the Otway site in southwestern Victoria, Australia, a field experiment is underway for aiming to detect CO2 leakage from shallow faults using the DFOS monitoring system. Fig. 4 is a cross-section showing the layout of a newly drilled injection well (Brumby 3), an observation well (Brumby 4) and two existing wells for the CO2 leakage detection test. In previous research by CO2CRC, an Australian research institute, a well was drilled through a shallow fault zone and DTS (temperature) was measured using OF cables. As the DTS monitors the temperature change at only a small range around the installed cables, we drilled two new wells with the newly developed OF cables installed for high performance DSS (strain). These OF cables are also available for DTS (temperature) and DAS (acoustic).

A CO2 injection test is scheduled in this summer. The CO2 will be injected at the injection well (Brumby 3) and some of CO2 gas will move toward the ground surface along the fault zone. We expect that the DFOS monitoring system at the observation well (Brumby 4) detects this CO2 migration.

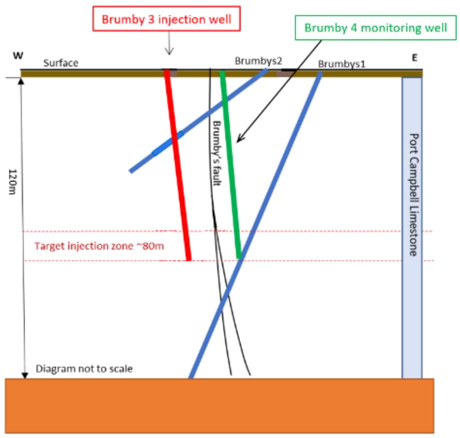

Fig. 4 Well layout at Otway site

2.2 SRM method development: development of cost estimation tool

As the Storage Resource Management (SRM) method development, we are developing a method for effectively utilizing the underground storage capacity (resource) at the CO2 storage site and a tool for evaluating the cost of the entire CCS project. The entire CCS project includes the stages of CO2 capture, transportation, and storage, and we aim to enable cost estimates corresponding to various options for CO2 emission sources, transportation methods, and injection amounts.

2.2.1 Features and configuration of the Tool

Our research group is developing the CCS cost estimation tool that allows even non-experts to appropriately estimate the cost of CCS, and that experts can also use for various CCS case studies. As for the specifications of the tool, in addition to trial calculations for individual cases, it is equipped with a mechanism that can collectively process multiple cases. And in addition to comparison studies for each case, studies that combine cases are also possible. The features of the tool under development are described below.

1) User friendly interface: The input interface has been devised so that the user can enter the necessary data appropriately without hesitation while looking at the screen, and can give instructions to execute calculations. If the screen is difficult to understand or the operation is complicated, the user cannot input specifications correctly, which leads to incorrect results or wastes operation time. Therefore, a easy and clear input interface is important. Fig. 5 shows the case selection screen. From this screen, it is possible to call up the specification confirmation screen and execute calculations.

Fig. 5 Case selection screen

In addition, the output interface is also important. Calculation results are output as a table on the web screen, but because they can be easily copied and pasted, they can be imported into Excel or dedicated graph creation software, and graphs can be created freely. By using the output from this tool, Fig. 6 shows CCS costs by transport volume and by distance in case of using pipelines and ships. It should be noted that the pipeline here is assumed to be an onshore type.

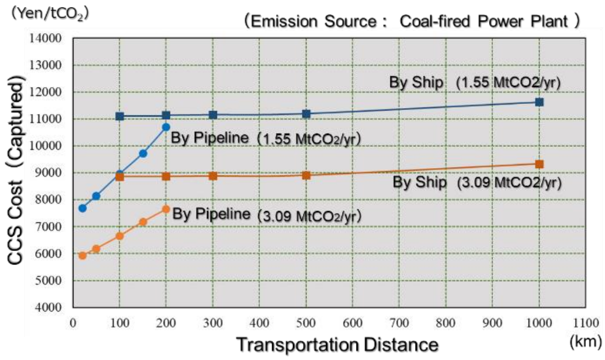

Fig. 6 CCS costs by transport volume and distance for pipelines and ships

2) Installation of DBMS (database management system): A general-purpose DBMS was installed for the purpose of easily and safely managing data in each study case for each user. It is also important to install the DBMS in order to make the interface, data management part and calculation engine independent. Completion of the cost estimation tool does not mean that the entire series of development ends. And continuous maintenance, such as rule changes, rule additions and data updates are required. This tool aims to improve maintainability by increasing the independence of each part.

3) Developed as a WEB system: No special operations of software or update are required on the user side, and it can be used only with a browser. Also, because all calculations are processed on the server, they are not affected by the capabilities of the user's PC or platform. Therefore, it is possible to use smartphones and pads in the meeting room to change specific specifications and to recalculate.

2.2.2 Development progress and future development plans

Fig. 7 shows the modules that have been installed so far (red frames) and the modules that are planned to be developed (blue frames).

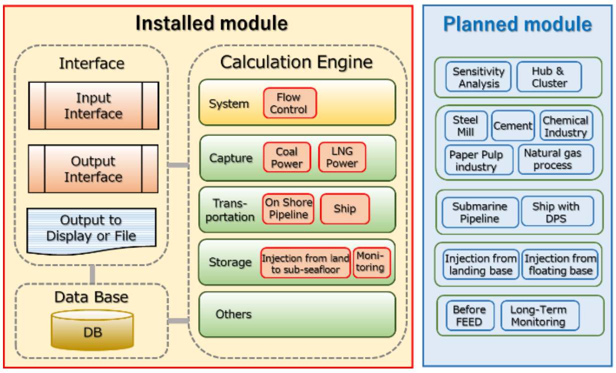

Fig. 7 Modules installed so far and modules to be developed

For capture, coal-fired power plants and LNG-fired power plants have already been installed. For transportation, it is possible to calculate "the pattern of land pipeline" and "the pattern of which, as one of ship transportation, loading from land and transporting it over the sea and then unloading it on land again". In the case of storage, it is possible to calculate the pattern of injecting water from the land into the sub-sea level with a sloping well. From now on, we plan to gradually develop the modules shown on the right side of the figure. In the coming modules, in addition to the cost calculation of each process, we plan to add calculation functions that extend the basic functions such as sensitivity analysis and hub & cluster.

In the first stage of development (until the end of FY2023), we plan to specialize in the trial calculation of the costs required for CCS. But in the future, we plan to develop them so that we can also use them for considering business models, by installing functions to calculate economic indicators that take incentives into account, etc.

2.3. Methodology for the Creation of Social Consensus (Social License to Operate, SLO)

The social consensus, including the local community, is essential to implement CCS projects. One of the key issues in the creation of social consensus (Social License to Operate, SLO) methodology is how business developers should communicate with residents so that they understand the need for CCS and support the project.

From the perspective of communication between business developers and residents, CCS business's significant character is the extremely low awareness of CCS among the general public. In a recent awareness survey, 14% of the respondents said they knew about CCS, and 42% said they had heard the word CCS. It was a situation that almost half of them had never even heard the word CCS. For this reason, the primary purpose of initial communication for CCS projects is to raise awareness of CCS, that is, to make residents get to know CCS.

The Barendrecht project in the Netherlands is a notable CCS project that was canceled due to opposition from residents. It has been pointed out that the reasons for residents' opposition were the lack of a lots of important aspects of risk communication, such as the fairness of procedures and trust. However, what is noteworthy here is that it is believed that the residents did not fully understand the CCS (project). Initially, residents were not considered as stakeholders and were not adequately informed. In addition, after the residents' opposition became apparent, providing of information from public was regarded by the residents as ``propaganda of the CCS supporters,'' and the providing of information to the residents did not function enough. Since the residents did not obtain sufficient information, it is possible that their opposition was not based on their understanding of CCS or the project. In other words, there is a possibility that the opposition was based on information heard from reliable people (celebrities, media, etc.) or many people. In such cases, decisions may be made based on wrong information. In fact, in Barendrecht 's case, the cover of a magazine is illustrated as a picture of a volcanic eruption spewing CO_2 out into the city, something that cannot happen. One of the importance of raising awareness of CCS in the early stages of the project is to increase the number of people who understand CCS and the CCS project and can decide whether to approve or disapprove of the project.

Literature on communication points out that it is important for business developers to listen to the opinions of residents/citizens and engage in dialogue (two-way communication) rather than giving one-sided explanations (one-way communication). However, this is not necessarily the case for communications in the early stages of a CCS project. Even if opportunities for dialogue are created, there is a risk that many people will not positively participate. It has also been pointed out that many people are unwilling to spend their precious time and effort to cooperate in solving social issues. Others may prefer passive (one-way) communication. In case of two-way communication, they feel that they must express their opinions, and feel a heavy mental burden. For this reason, it is considered important that the burden of participation is small and that it is easy to participate, rather than whether one-way or two-way communication, in the early stages of a project.

Lectures, exhibitions, and science cafes are held as scientific events to spread science and technology, especially to make people who have little interest in science and technology more familiar with science and technology. These scientific events are also suitable for early-stage communication events of CCS projects due to their low participation burden. However, many science events are known to have a very low participation rate of people who have little interest in science and technology, on the contrary to their purpose. However, even in science events, the participation rate of people with low interest in science and technology increases if the theme is related to their personal interests or directly related to their lives. From this point, it is considered necessary to hold two types of communication events in the early stages of CCS projects: events focused on science and technology, and events focused on matters directly related to people's lives.

Also, from the viewpoint of easiness for participation, it is effective to hold the event online. Due to the corona crisis, some of the events that had been held face-to-face until then were now held online, but there is a report that, thanks to the online event, people who had less participation in face-to-face events are now participating. However, while it is easy to participate in online events, it also has the disadvantage that it is easy to not concentrate on watching or to stop watching in the middle.

What has been described so far is only about communication at the beginning of the project. And the importance of two-way communication increases as the project plan becomes concrete. It is necessary for the business developer to have two-way communication with the residents and reflect the results in decision-making, instead of explaining the decisions made by the business developer to the residents and making them accept it. This becomes important for the smooth implementation of the project. In addition, in parallel with such events, public relations activities using the web, SNS, pamphlets, etc. are also necessary from the initial stage of the project in order to raise awareness of CCS and the CCS project.

Our research group is also creating a QA collection that can be referred to when explaining CCS to residents and answering questions from residents. It is said that the main fears and concerns that the general public feels about CCS are CO2 leakage and triggering of earthquake. Therefore, the QA collection particularly focuses on these two themes. A (Answer) is based on scientific knowledge including the research and development results of our research group so far, but we try to make the explanation understandable even without prior knowledge.

In order to reach agreement by residents and citizens, it is important that they come to understand CCS technology itself, and it is also important that they come to know the benefits of conducting CCS projects. In case of overseas CCS projects, they introduce the amount of investment and the increase in the number of employees which are brought by the implementation of the project. In case of facilities of about 1 million tons/year, which they regard as a commercial scale, it is reported that capital investment's amount of approximately 100 billion yen is expected. It is also reported that the employment effect is several thousand during construction and several dozen during operation. In the United States, it has also been shown that implementing CCS without decommissioning coal-fired power plants is effective in preventing unemployment and the decline of local industries. In this area, there is a coal mine adjacent to the coal-fired power plant. Since most residents are involved in power plants and the coal industry, the closure of coal-fired power plants will have a negative impact not only on residents, but also on the survival of municipalities. In Japan as well, there are concerns that the tax revenues of local governments will decrease dramatically due to the closure of oil refineries, ironworks, coal-fired power plants, etc., which are sources of large amounts of CO 2 emissions. CCS, as a decarbonization option, can contribute to sustainable regional operations, with substantial local benefits.

For the commercialization of CCS, it is necessary to envision a CCS business model that suits the situation in each region of Japan. We developed an emission source database to grasp CO2 emissions. CO_2 emissions were converted from summary results of greenhouse gas emissions which are based on thermal power generation handbooks and greenhouse gas emissions calculation, reporting, and publication system, and sorted out as direct emissions. The emission source database contains location information and it can be shown on maps. Even if the amounts of emissions from individual companies is small, grouping emission sources as a regional cluster will be useful in considering a hub-and-cluster approach to CCS. By integrating the emission source map and the potential capacity map of CO2 storage sites owned by RITE, we devised ways to make it easier to visualize the business image. Furthermore, by adding port information, it has become possible to plan transportation routes from emission sources to reservoirs, including not only land routs but also sea routes. Currently, we are also developing the CCS cost estimation tool, and are compiling the SLO method so that we can examine the merits of implementing CCS from an economic point of view as well.