CO_2 Storage Research Group

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Technology Demonstration for Practical Application of CO_2 Geological Storage, Commercialization Support and International Collaboration

1. Introduction

In the “GX Promotion Strategy” approved by the Cabinet in July 2023, the government announced its policy to support exemplary and advanced projects in order to create a business environment for the start of CCS projects by 2030. In response, Ministry of Economy, Trade and Industry (METI) and Japan Organization for Metals and Energy Security (JOGMEC) are supporting exemplary projects to establish business models that can be deployed across the nation as “advanced CCS projects” that provide integrated support for the entire value chain from CO_2 separation and capture to transportation and storage. Currently, a total of nine projects are underway that utilize domestic and international storage sites.

RITE is promoting the development of practical CO_2 geological storage technology for use in these CCS projects. RITE has organized the Carbon Dioxide Geological Storage Technology Research Association to collaborate with private companies and other organizations that are CCS providers, and is handling a wide range of technologies that contribute to improving safety and reducing costs in CCS projects, as commissioned by the New Energy and Industrial Technology Development Organization (NEDO), a national research and development agency.

Major themes include: technical demonstration of multi-sensing using optical fiber at domestic and overseas sites, development of evaluation methods for fault safety and integrity around CO_2 storage sites and development of a “CO_2 emission source database” and “CCS project cost estimation tool” that will be useful in the study of basic plans such as value chains and business models for CCS projects. In addition to the above, RITE is also conducting a survey on international trends in policies and technologies through collaboration with international organizations in the CCUS field as a NEDO-commissioned project. The results of these activities are introduced below.

2. Main research topics and results

2.1. Development of multi-sensing technology using optical fibers and field demonstration tests

In order to safely proceed with CO_2 geological storage, it is necessary to confirm through monitoring that the CO_2 injected into the reservoir remains in the reservoir, and that the pore pressure increase caused by the injection does not affect the shielding layer or the wellbore. The monitoring system must operate stably for a long time, have sufficient sensitivity, and be cost-effective. The distributed fiber optic sensing (DFOS) is a promising technology that meets these requirements. RITE is conducting research and development of this technology through laboratory and field tests, and is currently conducting long-term demonstration tests at sites both in Japan and overseas. Below, we explain the principle of optical fiber multi-sensing technology and introduce examples of demonstration tests at sites both in Japan and overseas.

2.1.1. Principle of distributed optical fiber multi-sensing

DFOS is being used in various fields as a technology that can obtain spatially continuous records because the entire fiber can act as sensors. An overview of the measurement principle is shown in Figure 1 (above). When an optical pulse is sent from one end of the fiber connected to an interrogator (measuring instrument), the scattered light is returned from various points along the fiber. By analyzing the scattered light using the interrogator, not only can the data be converted into physical quantities such as temperature and strain, but the reflection point position can also be identified by the arrival time of the scattered light. In addition, the scattering characteristics and measurement target differ depending on the wavelength of the scattered light (Figure 1 (bottom)). Raman scattered light is used for temperature measurement (DTS: Distributed Temperature Sensing), and Brillouin scattered light is used for temperature and strain measurement (DSS: Distributed Strain Sensing). Rayleigh scattered light is widely used in acoustic (DAS: Distributed Acoustic Sensing) measurements, but it is also used for high-precision temperature and strain measurements. These scattered lights need to be measured separately, but by installing a single cable that bundles multiple optical fiber strands, it can be used as a multi-sensor that can simultaneously capture temperature, strain, and acoustics (vibration) along the optical cable. The DFOS has many advantages over conventional monitoring devices such as thermometers and pressure gauges, including the fact that it has no electrical or mechanical devices, can be used in harsh environments deep underground, does not require a power supply, degrades little over time, and is not affected by electromagnetic radiation. It is expected to contribute to the cost reduction of geological storage monitoring.

The application of DTS, DSS, and DAS are described below, and also the main targets of the monitoring for geological carbon storages are summarized in Table 1.

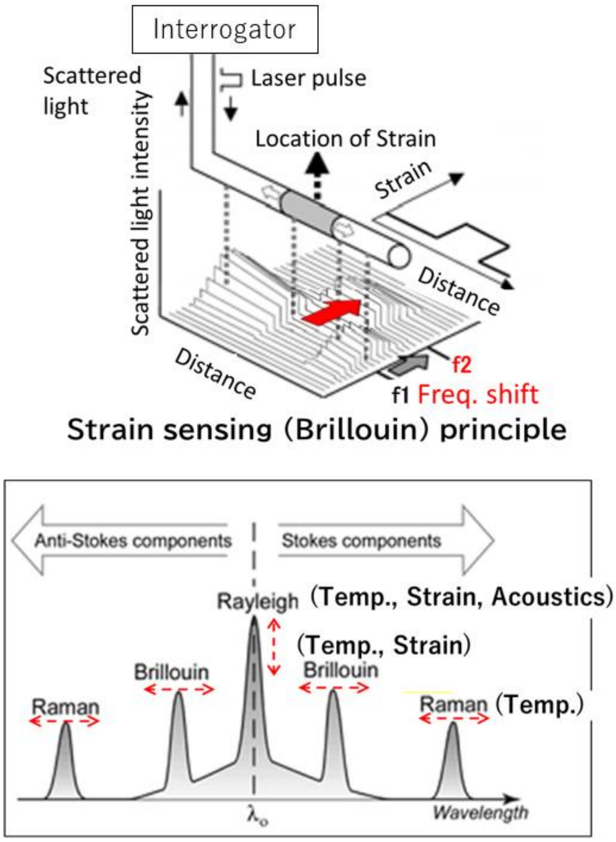

Figure 1 Principles of DFOS

Table 1 Application examples of DFOS

Measurement element	Monitoring targets
Temperature (DTS)	・The injection intervals in the reservoir ・Quality of well cementing ・CO_2 leakage from pipelines and injection wells
Strain (DSS)	・CO_2 intrusion into reservoir ・CO_2 leakage from reservoir ・Deformation of shielding layer during CO_2 injection
Acoustics (DAS)	・CO_2 distribution in the reservoir

2.1.2. Domestic Test Sites

At the test site in Mobara, Chiba Prefecture, field demonstration tests are being conducted for the purpose of developing technology for a CO_2 monitoring system using DFOS. To date, we have developed the fiber optic cables with high sensitivity for DSS that can be installed behind the well casing as well as improved installation operations for the newly designed cables in deep wells, and improved installation equipment. Through field tests at the site, we confirmed that optical cables can be installed behind the casing of wells over 900m deep without impairing the workability of the installation work, as long as the well walls are maintained during drilling (Figure 2). We are also using the installed optical fibers to develop a technology for evaluating the well integrity during cement laying. This technology evaluates the quality of cementing, which has a strong influence on fluid migration along the well, which is an artificial structure connecting the reservoir and the surface. Once the evaluation method identifies defective areas during cementing, it is expected that repairing the well before the start of injection will be possible.

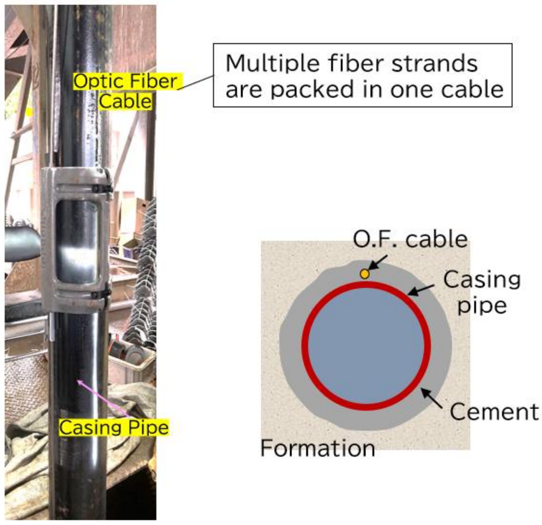

Figure 2 Fiber optic downhole installation

DSS measurements using Rayleigh scattered light were also carried out at the site (Figure 3). The results showed that strains of several tens of με due to fluid injection in nearby wells could be measured. Furthermore, differences in the geological layers and strains corresponding to fluid injection events were clearly confirmed. This result is an example of continuous in-situ acquisition of geological deformation due to fluid injection over time and space, and shows that it is a valuable measurement tool when considering CO_2

injection and ground deformation.

At present, long-term continuous DSS monitoring is being carried out at the site using optical fibers installed in the 900m well. The results of this monitoring are showing strain caused by groundwater pumping and injection around the site, and are expected to be used not only to evaluate the hydraulic properties of the surrounding area, but also to lead to evaluation technology for the effective placement of multiple wells, which will be essential for future geological carbon storages in Japan.

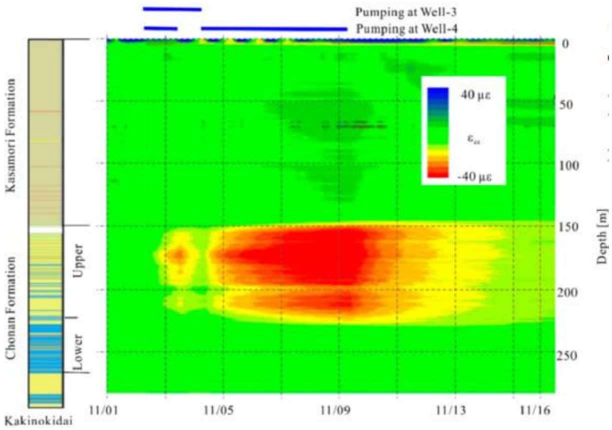

Figure 3 DSS measurement example at Mobara site

2.1.3. North Dakota CCS Site, USA

The North Dakota CCS project is a commercial project in which Red Trail Energy, Inc. is storing approximately 180,000 tons of CO_2 per year, which is recovered during the ethanol production process, in a saline aquifer approximately 2,000 meters deep. Injection begun in June 2022, and approximately 460,000 tons of CO_2 are stored as of the end of March 2025. In addition, the injection and observation wells at this site are wells approved as Class VI in the United States, and this is a demonstration test to be monitored under the US regulatory authorities.

In this project, optical fibers were installed along the wells and CO_2 pipelines (Figure 4), and simultaneous measurements of DAS, DTS, and DSS are ongoing to demonstrate multi-sensing technology. By continuing these measurements, knowledge is being collected on issues and countermeasures in the operation of the monitoring system that will contribute to domestic CCS projects. Below, we introduce examples of DAS and DTS results.

It is expected that the CO_2 plume subsurface is captured by DAS using fiber cables installed in the well. The VSP (Vertical Seismic Profiling), which is particularly suitable for monitoring CO_2 near the well with high accuracy, is a technology that is also used at various storage sites. The North Dakota site also adopts a new technology for the ground vibration sources.

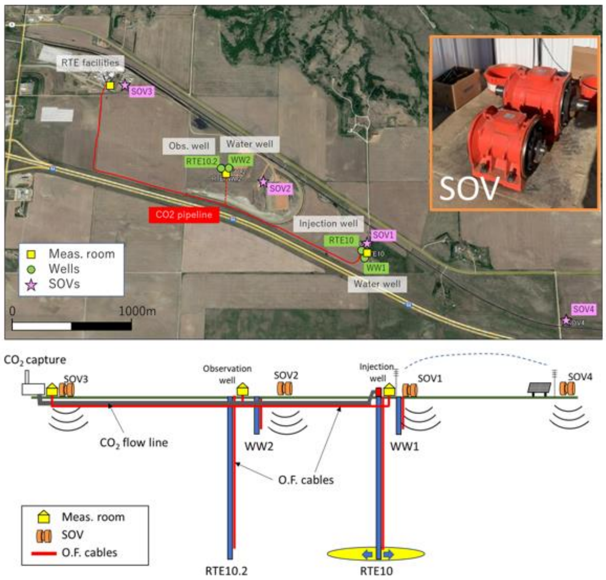

Figure 4 Overview of the optical fiber monitoring system at the North Dakota site and the location of the seismic seismometer

The repetitive seismic surveys are conducted every one to several years for cost considerations. To fill this gap between observations, permanently installed surface orbital vibrators (SOVs) were introduced to enable frequent data acquisition. SOVs transmit vibrations into the strata by rotating an eccentric weight. The control system of SOVs allows for scheduled oscillation by remote control and programming, so no on-site operator is required for SOVs operations. In addition, the data acquired from DAS can be automatically processed by an on-site PC, reducing the amount of data transferred to and from the site. At the North Dakota CCS site, SOVs are installed at four points at different distances from the injection well so that the gradual spread of CO_2 can be monitored immediately after the start of injection, and oscillation is performed every few days.

Figure 5 shows the DAS records of elastic waves emitted from an SOV installed near the injection well at a certain date and time, acquired by an optical fiber installed in the injection well, and the results of data processing. Figure 5a shows that the signal oscillated from the SOV is captured as a direct wave observed at the receiving point at each depth, and as a wave reflected and propagating upward at the formation boundary (reflected wave). In the VSP analysis, only the reflected waves from the received waves are extracted (Figure 5b) and converted to the same depth surface (Figure 5c), resulting in a nearly horizontal reflection surface. Furthermore, by adding multiple traces together, the image of the reflection surface near the wellbore is made clear (Figure 5d). Preliminary analysis confirms a trend toward slower elastic wave velocities in CO_2-infiltrated formations as the extent of CO_2 increases. In the future, it is expected that the spread of CO_2 will be imaged by comparing with the monitoring results of other SOVs and the injection history.

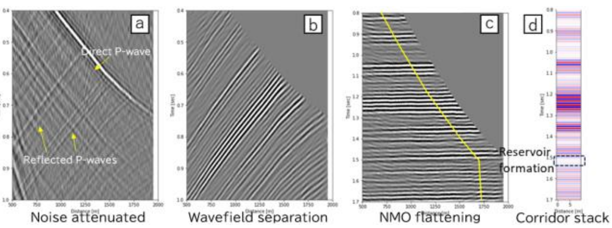

Figure 5 DAS/VSP recording and data processing examples

Next, we show an example of a DTS record obtained at the North Dakota site. Figure 6 shows the time and depth display of the DTS record in the injection well before and after the injection suspension period due to system maintenance, and the depth profile at a certain time section. The pre-injection period (baseline: left blue line in Figure 6) shows the geothermal gradient, whereas during the injection period, the injection well is cooled by CO_2, which is cooler than the ground temperature. Furthermore, during the injection shutdown period, the temperature of the injection well is captured as it returns to the surrounding formation temperature due to the cessation of CO_2 supply. As shown in these results, it was demonstrated that the temperature fluctuation of the entire injection well can be monitored in real time by DTS. Furthermore, if any trouble occurs along the well or pipeline equipped with optical fiber, it is expected that the location can be identified immediately.

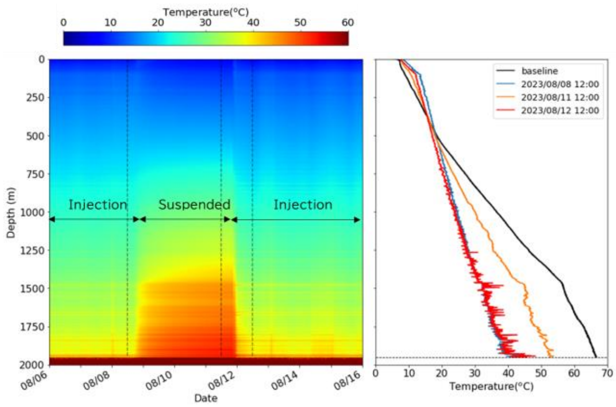

Figure 6 Example of injection monitoring using DTS

2.1.4. Australia Site

At the Australian site, we are conducting field demonstration tests with the DFOS technology to develop technology to evaluate the stability of faults against fluid injection and leakage from fault zones. Faults and cracks in geological strata are issues that must be considered as risks when advancing domestic CO_2 storage projects, and optical fiber multi-sensing technology is considered to be an effective means of monitoring them.

Therefore, in order to establish a technology for evaluating faults using optical fiber, a joint research project with an Australian research institute, which has a test site where known faults are distributed, was launched in FY2021, and field tests are being conducted.

At the Otway site in southwestern Victoria, Australia, testing is underway to detect CO_2 leakage from shallow faults, while the DFOS continues. The site is managed by the Australian research institute CO2CRC, and fluid injection tests were conducted from about the depth of 100 m of the well. RITE installed high-performance DSS fiber cables in newly drilled wells and measured strain during the tests. The depth distribution of the DSS results indicates the heterogeneity of the strata. We are currently examining the results of the seismic exploration to interpret the test results. In the future, we plan to conduct a leak detection performance evaluation test for small-scale CO_2 injection.

At the Perth South site in the southwest of Western Australia, field tests are being conducted to evaluate the stability of deep faults. The site is an existing test site (ISL: In-Situ Laboratory) managed in collaboration with the Australian research institute CSIRO, and the existence of a large fault zone several hundred meters deep is known (Figure 7). By the end of last year, the seismic survey was carried out to image the faults, observation wells were drilled, and optical fiber cables were installed in the well, and continuous DSS were performed. This year, a new well was drilled for fluid injection for the purpose of fault stability evaluation tests, and the geological properties were evaluated. In the future, a fluid injection test from this new well is planned to be carried out.

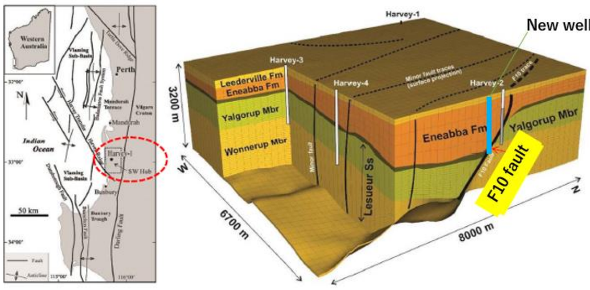

Figure 7 Faults and new well locations at the Perth South site

2.2. Support for CCS business plan development

The CCS Business Act was promulgated in May 2024, and the business environment for CCS is improving and CCS business development is progressing smoothly, with activities of advanced CCS support projects expanding.

RITE is also conducting research and development to support the development of large-scale CCS projects. Specifically, we are developing a CO_2 emission source database that will be useful in setting up a CCS project model and a CCS economic assessment tool that is necessary for evaluating the economic viability of CCS. Below, we will report on the details of each research and development project and introduce an example of a CCS project plan formulation support that combines them.

2.2.1. Development of a CO_2 emission source database

For the commercialization of CCS, it is important to appropriately match CO_2 emission sources with storage sites. Therefore, RITE is working on the development of a CO_2 emission source database (hereinafter referred to as emission source DB) to support this matching.

Below, we will introduce the data structure, functional overview, and future developments.

(1) Data structure of emission source DB

More than 10,000 pieces of CO_2 emission source information are registered in the public data based on the

Ministry of the Environment's "Greenhouse Gas Emissions Accounting, Reporting, and Publication System" (hereinafter referred to as "Global Warming Act Data"). The Emission Source DB uses this information as a base and takes the following steps a), b), and c) to suit the characteristics of decarbonization through CCS.

a) Estimation of direct CO_2 emissions and compilation of a database

The CO_2 emissions of each business site in the TOC data include CO_2 equivalent to electricity and heat supplied by others as a number.

CCS is intended to capture and store the direct CO_2 emissions actually emitted by the business site, so it is necessary to exclude CO_2 emissions equivalent to electricity and heat. Therefore, a "direct emission coefficient" is calculated for each business type using certain statistical processing, and this is multiplied by the CO_2 emissions under the Global Warming Act to calculate the direct CO_2 emissions from each business establishment, which are then entered into the database.

b) Incorporation of biomass fuel CO_2 emissions source information

The data in the Global Warming Law covers CO_2 emissions from fossil fuels, and CO_2 emissions from biomass fuels are not covered because they are carbon-neutral. On the other hand, biomass power plants also emit CO_2, which can be captured and stored for BECCS and negative emissions, which are important factors in promoting decarbonization. Therefore, we are also investigating CO_2 emission source information from biomass fuels with reference to information from the Agency for Natural Resources and Energy's Electricity Survey Statistics, etc., to estimate CO_2 emissions and incorporate them into an emission source DB.

c) Reflection of storage potential information

Storage potential mapping information from the "National Reservoir Resource Survey" conducted by RITE is also reflected in the emission source database.

(2) Realization of information mapping and screening functions

a) In order to properly match CO_2 emission sources and reservoirs, it is important to visually capture their location. Therefore, we realized a function to map the data shown in (1). Figure 8 is an example of such a mapping, which makes it possible to easily capture features such as emission sources are concentrated on the Pacific Ocean side and storage sites are mostly located on the Japanese side.

Figure 8 Example of integrated display of CO_2 emission sources and storage potential

b) Information Screening Function

The visualized map can be freely moved and specific locations can be zoomed in on. Furthermore, by drawing a rectangle around a certain area, information on the CO_2 emission sources in that area can be extracted, which can be used for clustering emission sources. Furthermore, it is possible to display information by emitting business, such as coal-fired power plants and factories. For example, by displaying only CO_2 emission sources from biomass fuels, it can contribute to the planning of CO_2 emission offset strategies through the conversion to BECCS.

This database is available for general use to those who wish to try it from November 2024. If you are

interested, please refer to the following
https://www.co2choryu-kumiai.or.jp/business/theme/

(3) Aiming to predict and display future developments of CO_2 emission sources

The full-scale deployment of CCS requires a long-term effort, and the composition of thermal power plants and factories is expected to change during that time. Therefore, we have begun developing a function that predicts changes in CO_2 emission sources from 2025 to 2050, incorporates this information into the CO_2 emission source database, and displays the time-series changes in emission sources on a map.

We are currently proceeding with the development of this system with reference to the carbon neutralization plans for coal-fired power plants published by electric power companies, but we would like to expand this system to large-scale factories after obtaining knowledge from related parties. We would appreciate your cooperation.

2.2.2. Development of a CCS economic cost estimation tool

In the commercialization of CCS, it is essential to set up an appropriate business model that takes into account economic feasibility, including the combination of emission sources and storage sites, and the transportation routes and technology methods that connect them. To this end, it is effective to utilize the CO_2 emission source database and cost estimation tool described above in an integrated manner.

The following is a description of the basic functions and configuration of the cost estimation tool that RITE is developing, as well as the flow of cost estimation.

(1) Basic Functions

CCS is divided into capture, transportation, and storage processes, and the tool can calculate CAPEX and OPEX per t-CO_2 for each of these processes. Figure 9 shows the modules in the calculation engine.

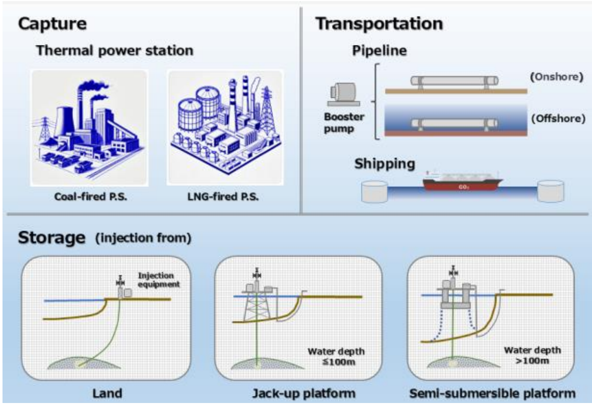

Figure 9 Modules installed in the calculation engine

In terms of capture, estimates are currently available for coal-fired and LNG-fired power plants. In the future, we plan to address emission sources in the industrial sector, such as steel mills and cement plants.

For transportation, the tool supports both land-based and submarine pipeline transportation and ship transportation. For vessel transport, the number and size of vessels that meet the operating conditions are automatically calculated by entering the required parameters, such as transport distance, sailing speed, and number of standby days.

For storage, the system automatically selects one of three technical methods depending on the distance from shore and water depth. For offshore distances of 3 km or less, the method in which an inclined well is injected from land is selected. For offshore distances of more than 3 km, the bottom-fixed type is selected when the water depth is less than 100 m, and the floating type is selected when the water depth is deeper than that.

(2) Tool function configuration

The cost estimation tool consists of three functions in addition to the input interface (Figure 10).

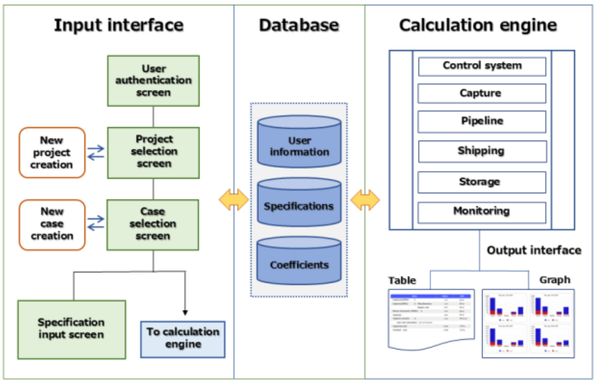

Figure 10 Functional configuration of the cost estimation tool

The input interface is a function that allows the user to input calculation specifications and send instructions to the tool.

The database holds authentication information, calculation specifications, and various coefficients and tables used in the calculations.

The calculation engine is a unit that calculates costs based on specifications. There are multiple modules, such as capture, pipeline transportation, ship transportation, storage, and monitoring, which are executed sequentially under the control of the calculation control program. The calculation engine also implements an output interface function for the calculation results (display of tables and graphs).

(3) Cost estimation process

a) Setting calculation conditions and preparing specifications

First, a business model is established, including the location of the emission source and storage site, the transportation route, and the technology method. Next, specifications such as the business period, CO_2 processing volume, discount rate, exchange rate, transportation distance, transportation method, storage depth, and injection rate are prepared. Since some of these are closely related to management policies and strategies, it is desirable for business planners and analysis engineers to work together to consider them.

b) Use of tools

This tool is a web tool and can be accessed using a standard browser (Edge, Chrome, etc.) anywhere with an internet connection.

The data entry screen (Figure 11) is prepared for each process, such as capture, transportation, storage, and monitoring, and the screen can be switched by tabs. After entering all items, save and return to the case selection screen (Figure 12) and instruct to execute the calculation.

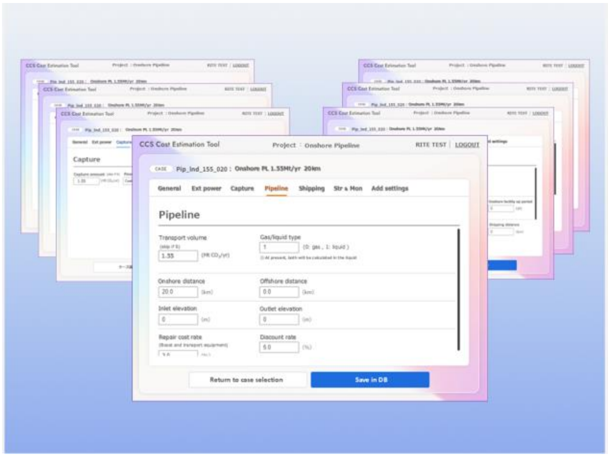

Figure 11 Specifications input screen

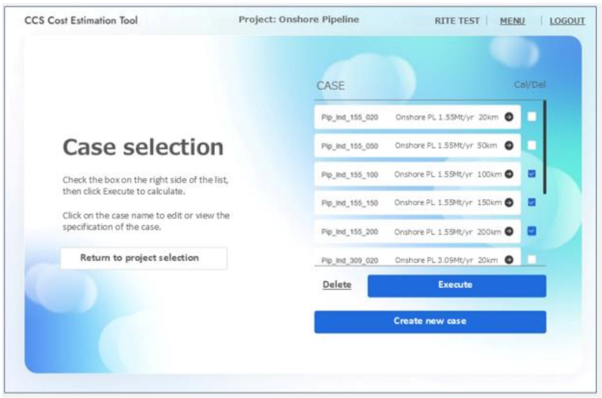

Figure 12 Case selection screen

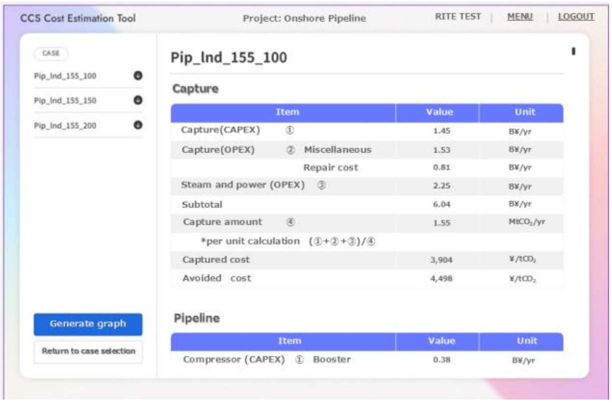

Figure 13 Output screen of the calculation results (table)

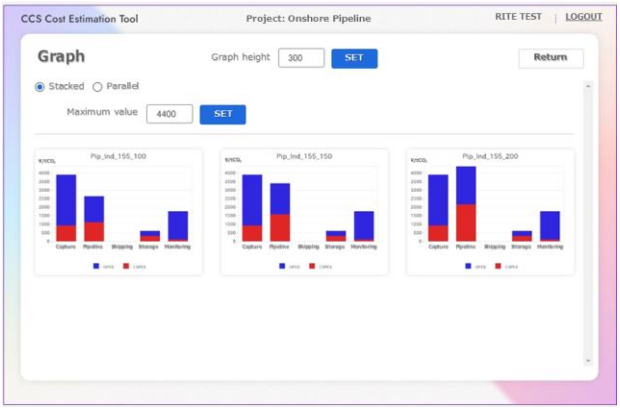

Figure 14 Output screen of trial calculation results (graph)

When the calculation is completed, the costs for each process are output in table format, followed by a list of the calculation specifications (Figure 13). There is also a function to display the costs in graph form (Figure 14). The graph shows the costs for each process, broken down into CAPEX and OPEX, and is designed to display the costs for multiple cases on the same screen so that they can be compared.

2.2.3. Examples of CCS business plan formulation support

We have introduced the functions and usage examples of the CO_2 emission source database and the CCS cost estimation tool so far, and below we will introduce an example of formulating a CCS business plan that combines these.

(1) Setting the business model

As a CCS project, “the basic plan is assumed to be “Two LNG-fired power plants in the Tokyo metropolitan area will be selected as emission sources, and the CO_2 captured there will be stored in the Japan Sea area.”

To materialize the plan, the CO_2 emission source database was used to set up an LNG-fired power plant and a port for transporting the captured CO_2. The Japan Sea area was selected as the storage point, and the transport distance (ship and pipeline transport) was determined.

(2) Economic evaluation and business plan consideration

In order to evaluate the economic viability of the above business model, first set the specifications as shown in Figure 15 and calculate the overall business cost using a economic assessment tool.

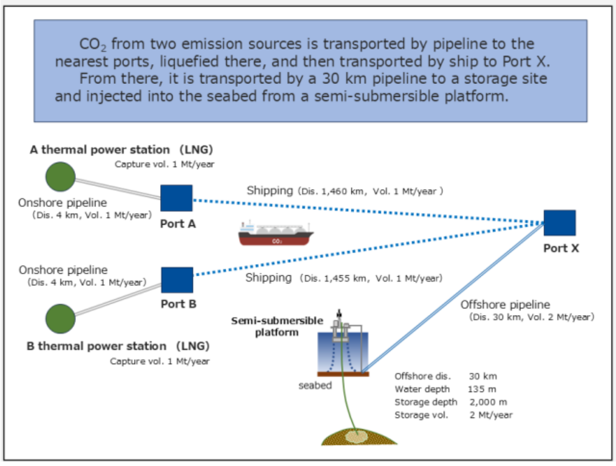

Figure 15 Specifications for cost calculation

In order to optimize the business model, it is necessary to use this as a base case and analyze and evaluate it through case studies.

As an example, we estimated the costs of consolidating CO_2 sending ports A and B into one and replacing ship transport with pipeline transport. The results quantitatively show that cost reductions are possible through port consolidation or pipeline transport (Table 2).

Table 2. Cost estimation case study (example)

case	Cost (relative value)
base	100
Port consolidation	95
Pipeline Transportation	85

In this example, a very simple case was used, but even when multiple business models are used, economic evaluation can be performed quickly by linking the CO_2 emission source database with the CCS cost estimation tool. It is effective as a tool to support efficient business plan formulation.

2.3. International CCS Trends

In order to achieve the goal of commercializing CCS by 2030 as set out in Japan's long-term CCS roadmap, efforts are being made to resolve institutional and technical issues, such as establishing financial incentives, reducing costs through expansion of scale, and promoting Japanese technology overseas.

RITE, aiming at utilizing in discussions on the dissemination of CCS, cooperates with relevant international organizations where efforts have been gaining momentum in recent years, as well as international conferences such as the London Convention on Subsea Storage of CO_2 and Transboundary Transport, collects information at each conference, and disseminates Japan's efforts.

Additionally, we are investigating international trends such as CCS financial support systems and project scale expansion through interviews and literature surveys.

We introduce trends in major countries, with a focus on Europe where support systems and projects have become more active in recent years as followings.

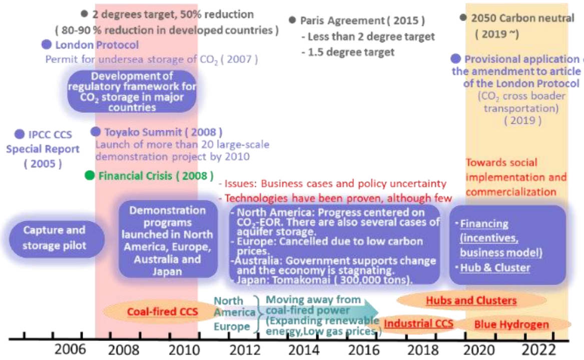

Figure 16 Changes in global regulations and incentives

2.3.1. Background to the introduction of CCS in Europe, policy priorities, etc.

(1) Climate change measures

In response to the 50% reduction by 2050 (80-90% reduction in developed countries) at the 2009 G8 Summit, etc., emissions trading systems and regulatory frameworks for CO_2 storage were established in major countries and demonstration projects, etc. were launched. But some CCS projects were cancelled in Europe due to stagnant carbon prices and expansion of renewable energy.

On the other hand, with more than 100 countries declaring carbon neutrality by 2050 at COP25 in 2019 in response to the Paris Agreement, international understanding has developed that CCS, CDR (CO_2 removal), etc. are essential for hard to abate sectors (cement, steel, oil refining, air transportation, etc.) where CO_2 emissions are inevitable by methods of electrification and hydrogenation, Carbon management policies in each country have been strengthened.

(2) Achieving net zero emissions in the industrial sector and securing CO_2 storage capacity

The Council of the European Union (EU) approved the Net-Zero Industry Act in 2024, setting a goal of securing 50 million tons of CO_2 storage and injection capacity per year in the EU by 2030 in order to reduce emissions from the industrial sector.

(3) The need for international CO_2 transport

infrastructure

In its Industrial Carbon Management Strategy, the EU cited the need for international CO_2 transport infrastructure in addition to storage capacity for CO_2 that cannot be stored or used at capture sites and to create a single EU carbon market.

(4) The need for financial support systems

At present, the carbon price under the emissions trading system, which represents the cost of CO_2 countermeasures without introducing CCS, is smaller than the costs of capture, transportation, and storage. At the same time, it is currently difficult to pass on all the introduction costs to customers. Therefore, it is recognized that public support is important for the implementation of CCS.

(5) Promoting hubs and clusters

Emphasis is being placed on hubs and clusters of emission sources and transport and storage infrastructure, from the perspective of reducing costs by bundling multiple projects on a larger scale and prioritizing decarbonization of industrial clusters.

2.3.2. Trends in Europe

(1) EU

To promote the development of international CO_2 transport infrastructure, the CEF-E (Connecting Europe Facility for Energy) Fund, which supports trans-European energy infrastructure, supports cross-border CO_2 transport projects, etc. In addition, the EU Innovation Fund, which is funded by revenues from the EU-ETS, supports CO_2 capture in the industrial sector, etc.

Improvements to the EU Emissions Trading Scheme (EU-ETS) are also underway. EU plans to phase out the free allocation of emission credits to specific industries by 2034. The free allocation is intended to prevent carbon leakage (transfer of production to other countries with less stringent regulations, etc.), but on the other hand, it is a response to the problem of undermining incentives for investment in emission reductions. In addition, a carbon pricing on imports goods equivalent to that in the EU (Carbon Border Adjustment Mechanism (CBAM)) will be introduced.

(2) United Kingdom

UK is promoting CCS with an emphasis on the transition to net zero and employment and economic growth through CCS, with a goal of 20 to 30 million tons per year by 2030. Four clusters that will be operational by 2030 have been selected, and support of approximately 22 billion pounds for two of them was announced by the Prime Minister, the Minister for Energy Security and Net Zero, and the Chancellor of the Exchequer in autumn 2024. Licenses for transportation and storage have also been granted to operators, and an investment decision was made for the East Coast cluster at the end of 2024.

Targets for introduction have been set for each of the following sectors: manufacturing, waste treatment, blue hydrogen, power generation, and CDR (CO_2 removal, BECCS (capture and storage from biomass combustion) and DACCS (direct air capture and storage)), and support programs have been designed to enhance the predictability of the projects. The support system is highly compatible with existing renewable energy support systems and focuses on price differences, specifically, support for price differences between CCS costs and CO_2 control costs such as EU-ETS prices.

(3) Norway

Norway has abundant oil and gas resources and saline aquifers in the North Sea, and has a track record of working on the world's first CCS project for storing in saline aquifers.

Anticipating the development of a European storage hub, the government is supporting the international capture, transportation, and storage project (Longship) for manufacturing industries or so with subsidies and carbon tax exemptions. The facility for the transportation and storage process (Northern Lights) has been completed, and CO_2 shipping and storage from a domestic cement plant or so is scheduled to begin in 2025, with plans to import from the Netherlands, Denmark, and other countries (initial capacity of 2.5 million tons/year). Northen Lights project has received approximately 130 million euros from the CEF-E fund and has decided to make additional investments, including imports from Sweden, with plans to expand capacity to more than 5 million tons/year.

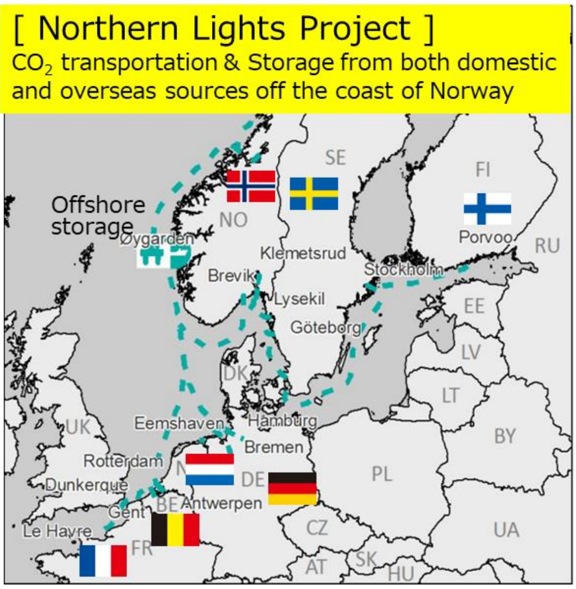

Figure 17 Northern Lights Project (cross-border transport and storage)

Source: Northern lights project. Project of Common Interest, European Union,
https://ec.europa.eu/energy/maps/pci_fiches/PciFiche_12.4.pdf

(4) Netherlands

The Climate Act in 2019 sets a target of reducing CO_2 emission by 49% by 2030 (compared to 2019). The plan is to utilize offshore CO_2 storage sites and use CCS to address roughly half of industrial emissions. For this purpose, from 2020 the scope of financial support systems for existing renewable energy power generation etc. was expanded, and price differential support for capture, transportation and storage was started.

Four capture projects were selected in Rotterdam in 2020, which will use the Porthos project, the EU's first transportation and storage hub.

The Porthos project (2.5 million tons/year) began construction in 2024, with operations scheduled to start in 2026. The onshore pipeline will be built with a final capacity of 10 million tons/year, anticipated to be shared with the planned international CO_2 transport and storage project (Aramis) which receives approximately 100 million euros from the EU CEF-E fund.

(5) Denmark

In the Climate Act of 2020, the goal is to reduce GHG emissions by 70% by 2030 (compared to 1990 levels) and to achieve carbon neutrality by 2050.

For CCS, the government supports price differentials for installation costs and selected the Ørsted project to export CO_2 from a biomass power plant to the Northen Light project in Norway in the first round of public bidding. In addition, the Greensand project received CO_2 from Belgium and succeeded in the world's first transboundary ship transportation and injection in 2023.

(6) Germany

It is aimed to reduce GHG emissions by 65% by 2030 (compared to 1990 levels) and to achieve carbon neutrality by 2045. However, a federal government report recommended issues such as the fact that the existing legal framework does not allow CO_2 pipeline transportation. As a result, the basic principles of the carbon management strategy were approved by the Cabinet, and based on this, a bill to amend the Carbon Storage Act was submitted to the Diet in 2024.

Additionally, support for climate change measures in the industrial sector began in 2024. As mentioned above, due to delays in the development of legal regulations, public bidding for support for CCS projects are scheduled to begin after 2025.

2.3.3. Trends in North America

The United States and Canada lead the world in terms of progress and deployment of CCS projects, with more than 20 projects in operation.

(1) United States

CCS projects in the U.S. are largely due to the existence of 4,000 miles of CO_2 pipelines and numerous CO_2-EOR sites that have been developed since the 1970s for CO_2-EOR (enhanced oil recovery).

CCS has been supported since 2008 by granting tax credits based on the amount of CO_2 geological storage. Since then, support for tax credits has been strengthened several times, and CCS projects, especially for low-cost ethanol plants have been increasing and DAC has also been added to the list. In addition, subsidies to support CCS in cement and other manufacturing industries with high recovery costs and low-interest loans to support CO_2 transportation infrastructure are being provided

(2) Canada

Although Canada is a resource-rich country, it is working on carbon neutrality by introducing CO_2 emission regulations such as a carbon tax.

Large-scale CCS projects are being implemented in Alberta and Saskatchewan, where oil and gas production is active.

Support measures for CCS vary from province to province, and Alberta, for example, has been supporting CCS projects by granting CO_2 credits. Alberta has also selected projects for hubs and is providing support for exploration costs. Meanwhile, the federal government's investment tax credit was enacted in 2024, supporting collection, transportation, storage, utilization, and DAC, and also providing support by investing in CCS projects through a fund.

2.3.4. Trends in Australia

Australia is a resource-rich country with large exports of LNG and coal, and is promoting decarbonization in all sectors, including oil and gas operations, with the goal of carbon neutrality in 2050 and a 43% reduction by 2030 (compared to 2005 levels). The safeguard mechanism sets an emissions cap for large emitters of 100,000 t-CO_2 or more per year, requiring them to contribute to carbon neutrality by 2050, and the cap will be reduced by approximately 5% each year until 2030. This makes it difficult to release CO_2 associated with natural gas production into the atmosphere, making the application of CCS inevitable. The Gorgon project, which stores CO_2 associated with natural gas production on land, began operation in 2019 and Japanese companies are participating.

There is also storage potential in ocean area (offshore), and exploration permits for 10 areas were opened to the public in 2023, so offshore CO_2 storage is expected to expand in the future.

There is also growing interest in CCS hubs to capture CO_2 emissions from LNG, hydrogen, ammonia production and industrial sectors.

Federal support is provided through the granting of carbon credits. The Moomba project (operational in 2024), which store CO_2 from the LNG plant in an onshore depleted gas field and serve as a CCS hub, is receiving this support.

The state of Victoria, which has abundant storage potential, is planning to build a CCS hub with funding from the federal government (CarbonNet project). The project involves transporting CO_2 via pipeline to offshore reservoirs, and FEED (basic design) has now been completed. The Japanese government agencies and a CCS-related company have also taken notice, and have established a cooperative framework, including signing an MOU with the state government.

The federal government is also working to establish laws regarding the import and export of CO_2. The Bayu-Undan project, which aims to store CO_2 in a depleted gas field in Timor-Leste's territorial waters, is planned in conjunction with gas field development by an

Australian company, and there are also plans to receive and storage CO_2 from other countries as a CCS hub.

The Moomba project mentioned earlier is also studying to receive CO_2 from Japanese companies, and Japanese companies are also involved in several other CCS projects as partners.