CO_2 Storage Research Group

Member (As of Apr. 2026)

Group Leader, Principal Research Scientist	**Ziqiu Xue**
Deputy Leader, Principal Research Scientist	**Nobuo Umeda**
Principal Research Scientist	**Satoru Yokoi**
Principal Research Scientist	**Takahiro Nakajima**
Principal Research Scientist	**Yasuhide Nakagami**
Principal Research Scientist	**Makoto Nomura**
Vice Principal Research Scientist	**Nobuo Takasu**
Vice Principal Research Scientist	**Tsutomu Hashimoto**
Vice Principal Research Scientist	**Saeko Mito**
Senior Research Scientist	**Tetsuma Toshioka**
Senior Research Scientist	**Hyuck Park**
Senior Research Scientist	**Keisuke Uchimoto**
Senior Research Scientist	**Hironobu Komaki**
Senior Research Scientist	**Atsushi Ibusuki**
Senior Research Scientist	**Yuji Watanabe**
Senior Research Scientist	**Osamu Takano**
Senior Research Scientist	**Jiro Suekuni**
Senior Research Scientist	**Ken Asajima**
Senior Research Scientist	**Tetsumi Imamura**
Chief	**Kimiko Nakanishi**
Chief	**Akemi Nishide**
Chief	**Megumi Okumichi**
Research Scientist	**Takayuki Miyoshi**
Research Scientist	**Takeya Nagata**
Research Scientist	**Rasha Amer**
Research Scientist	**Jinrong Cao**
Research Scientist	**Masafumi Kotani**
Research Scientist	**Hiraku Miyasaka**
Research Scientist	**Wataru Ouchi**
Research Scientist	**Barry Majeed Hartono**
Research Assistant	**Junko Hirai**
Research Assistant	**Yuko Himi**
Research Assistant	**Megumi Sasaki**
Research Assistant	**Asato Murai**
Research Assistant	**Asuka Nakamura**
Staff	**Nae Hidaka**
Staff	**Mari Okuda**

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

1. Introduction

The CCS Business Act was promulgated in May 2024. While the provisions for exploration and exploratory drilling have already been enacted, the necessary government ordinances and ministerial regulations are currently being finalized to implement transportation and storage operations. Simultaneously, nine advanced CCS projects are underway, led by Ministry of Economy, Trade and Industry (METI) and Japan Organization for Metals and Energy Security (JOGMEC). Among these, exploratory drilling has commenced offshore Tomakomai, Hokkaido. Following the drilling and evaluation of two exploratory wells, the Final Investment Decision (FID) is scheduled for fiscal year 2026. Furthermore, efforts toward operational launch are progressing, with procedures for exploratory drilling underway offshore Kujukuri, Chiba Prefecture.

RITE has been advancing the development of technologies essential for practical-scale geological CO_2 storage, specifically tailored for application in these CCS projects. Through Research Institute of Innovative Technology for the Earth (RITE), we have organized Geological Carbon Dioxide Storage Technology Research Association. In collaboration with private companies poised to become CCS operators, and as part of a project commissioned by New Energy and Industrial Technology Development Organization (NEDO), we are engaged in a wide range of initiatives to enhance the safety and cost-efficiency of CCS operations.

Our core research focuses on the technical demonstration of CO_2 injection and storage monitoring using optical fiber sensing, the development of methodologies to evaluate fault safety and integrity surrounding CO_2 storage sites, and the construction of resources such as a "CO_2 Emission Source Database" and a "CCS Project Cost Estimation Tool," both of which are critical for evaluating value chains and business models. Additionally, we are conducting international surveys on policy and technical trends through partnerships with global CCUS organizations, also under the auspices of NEDO. The results of these activities are presented below.

2. Main research topics and results

2.1. Development and Field Demonstration of Multi-Sensing Technology Using Optical Fibers

To ensure the safety of CO_2 geological storage, continuous monitoring is essential to verify that injected CO_2 remains confined within the storage reservoir and that the resulting increase in pore pressure does not compromise the integrity of the caprock or the wellbore. Monitoring systems must be both long-term stable and cost-effective. Distributed Fiber-Optic Sensing (DFOS) is a highly promising technology that meets these requirements. RITE has been advancing the research and development of this technology through laboratory experiments and field trials, and is currently conducting long-term demonstration tests at various sites in Japan and abroad. This measurement technology is expected to play a critical role in the safety management of CO_2 geological storage throughout the entire project lifecycle, from initiation to completion.

2.1.1. Principle of distributed optical fiber multi-sensing

Distributed Fiber-Optic Sensing (DFOS) is increasingly adopted across various sectors because it allows for spatially continuous measurements by utilizing the entire length of the optical fiber as a sensor. The measurement principle is illustrated in Figure 1. When a laser pulse is transmitted through the fiber, backscattered light is reflected from various points along the fiber. The interrogator analyzes the backscattered light and calculates shifts in temperature or strain by comparing the signal against a baseline (initial state). By measuring the round-trip time of the scattered light, the precise location of the disturbance can be determined. Furthermore, the characteristics of the scattering vary based on the wavelength of the light, corresponding to different measurement parameters (Figure 1, bottom).

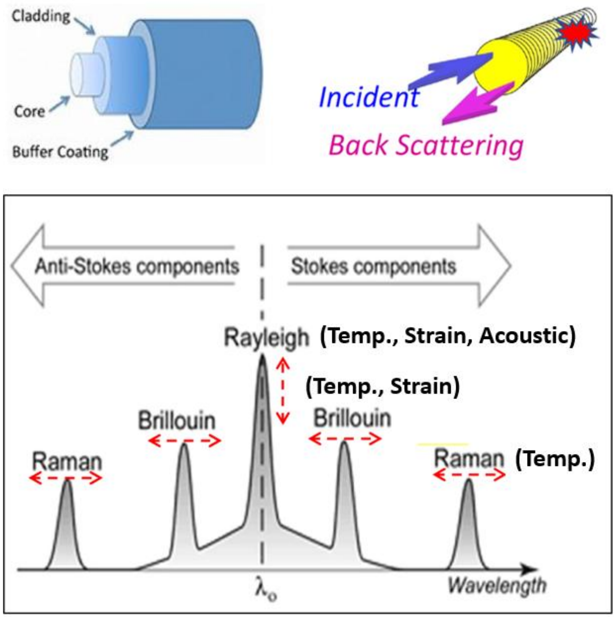

Figure 1: Principles of Distributed Fiber-Optic Sensing (DFOS) illustrating Rayleigh, Brillouin, and Raman backscattering components for multi-sensing applications.

Different scattering phenomena are utilized for specific sensing applications: Raman scattering is used for Distributed Temperature Sensing (DTS), while Brillouin scattering is employed for both temperature and strain sensing (Distributed Strain Sensing, DSS). Rayleigh scattering is widely used for Distributed Acoustic Sensing (DAS), though it is also utilized for high-precision temperature and strain measurements. While these scattering components must typically be measured individually, a multi-core or multi-strand fiber cable allows for the simultaneous monitoring of temperature, strain, and acoustics along the entire length of the cable.

The primary advantage of DFOS is that the sensing cable contains no electrical or mechanical components; it is entirely passive. This enables deployment in the harsh, high-pressure, and high-temperature environments typical of deep underground geological formations. Additionally, the fiber's small diameter allows for installation in confined spaces. Compared to conventional monitoring systems (e.g., discrete electronic thermometers and pressure gauges), DFOS provides superior long-term reliability with negligible degradation and immunity to electromagnetic interference.

Table 1 summarizes the potential measurement parameters and applications for geological CO_2 storage. Temperature (DTS) and strain (DSS) data, obtained from optical fibers installed on the exterior of the casing in injection and observation wells, facilitate:

-Identification of the active CO_2 injection zones within the reservoir.

-Assessment of injection efficiency and formation permeability.

-Real-time monitoring of caprock deformation and detection of potential fluid migration along the wellbore annulus.

Meanwhile, acoustic sensing (DAS) acts as a high-density seismic array, enabling the monitoring of underground CO_2 plume at any point during operations. Consequently, DFOS is expected to significantly contribute to the overall cost-efficiency of CCS projects. The following section presents specific field demonstration results conducted by RITE.

Table 1 Application examples of DFOS

Measurement element	Monitoring targets
Temperature (DTS)	・The injection intervals in the reservoir ・Quality assurance of well cementing CO_2 leakage from pipelines and injection wells
Strain (DSS)	・Characterization of CO_2 plume intrusion into the reservoir ・Detection of potential CO_2 leakage from the storage formation ・Monitoring of caprock integrity
Acoustics (DAS)	・Mapping of CO_2 plume and plume migration within the reservoir

2.1.2. North Dakota CCS Site, USA

The North Dakota CCS project is a commercial-scale operation managed by Gevo North Dakota (formerly Red Trail Energy). The project involves the sequestration of approximately 180,000 tons of CO_2 annually—captured from a corn-based ethanol production process—into a deep saline aquifer located at a depth of approximately 2,000 meters. Injection operations commenced in June 2022, and as of the end of March 2026, cumulative CO_2 storage has reached approximately 640,000 tons. The injection and observation wells are certified as Class VI wells under U.S. regulatory frameworks, providing a robust platform for real-world demonstration of mandatory monitoring protocols.

RITE has deployed fiber-optic cables along the wellbores and CO_2 pipelines (Figure 2) to demonstrate multi-sensing technology through the simultaneous acquisition of DAS, DTS, and DSS data. This long-term monitoring campaign is critical for identifying operational challenges and developing technical countermeasures that will serve as a foundation for future domestic CCS projects. Representative results from the DAS and DTS measurements are detailed below.

Seismic Monitoring with Surface Orbital Vibrators (SOVs)

Distributed Acoustic Sensing (DAS) utilizing well-installed fiber cables provides a high-resolution window into subsurface CO_2 plume migration. In particular, Vertical Seismic Profiling (VSP)—a technique widely employed in CO_2 storage and geothermal sites—is highly effective for high-precision monitoring near the wellbore. At the North Dakota site, we have introduced an innovative seismic source technology: the Surface Orbital Vibrator (SOV).

SOVs generate seismic waves by rotating an eccentric mass, transmitting vibrations into the subsurface. Four SOV units have been installed at the site (Figure 2) to capture the gradual spatial evolution of the CO_2 plume as injection progresses. The system is fully automated and programmable, allowing for remote activation at any time. Furthermore, DAS data processing is performed in real-time via on-site computing, which significantly reduces the data transfer requirements between the site and the research office.

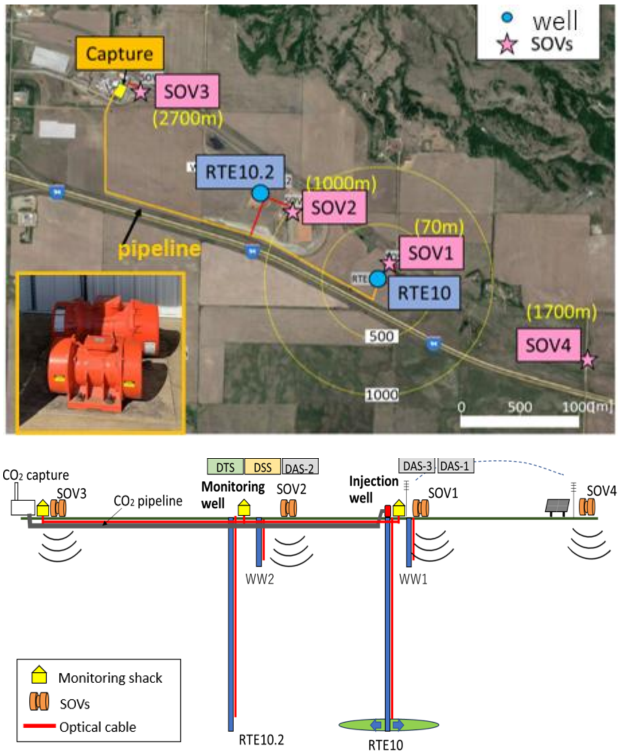

Figure 2: Layout of the integrated monitoring infrastructure at the North Dakota site, showing the alignment of optical fiber cables, CO_2 pipelines, injection/observation wells, and Surface Orbital Vibrators (SOVs).

Strategic Advantages of Continuous Monitoring

Figure 3 illustrates the conceptual distinction between conventional time-lapse (4D) seismic surveys and continuous monitoring using SOVs. Routine 3D seismic surveys are typically conducted at five-year intervals due to high costs. The primary advantage of the SOV system is its ability to provide high-frequency data acquisition, effectively "filling the gap" between conventional survey cycles. By capturing short-term, high-resolution snapshots of the CO_2 plume migration, the frequency of expensive, large-scale seismic surveys may be reduced. Additionally, the remote operation capability of the SOV system eliminates the need for on-site personnel, offering a safer, more autonomous, and cost-effective monitoring solution for long-term storage projects.

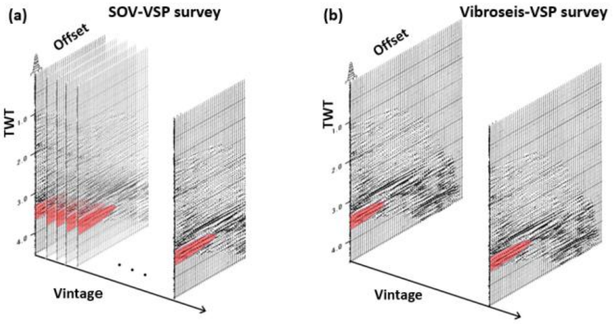

Figure 3: Conceptual comparison between high-frequency continuous monitoring using SOVs and discrete conventional 4D seismic surveys.

Data Analysis: Seismic Waveform Processing

For the data analysis derived from SOV excitation and DAS measurements, the seismic signal is first processed to separate direct down-going waves from the reflected up-going waves; the latter contain essential information regarding the target reservoir (Figure 4a). Next, the reflected waves from stratigraphic boundaries are converted into the Two-Way Travel Time (TWT) domain. Finally, by mapping the data chronologically against the cumulative CO_2 injection volume, we can characterize the impact of CO_2 plume migration on seismic reflections.

Figure 4b illustrates the monitoring results from the SOV located closest to the injection well (approximately 70m offset). Data indicate that once the cumulative injected CO_2 volume exceeds approximately 5,000 tons, distinct changes in the reflected waves occur within both the reservoir and its underlying layers. Specifically, in the later phase, the red and blue bands exhibit a downward curvature, indicating an increase in the travel time of the reflected waves (time-delay). This phenomenon demonstrates a reduction in P-wave propagation velocity caused by the substitution of pore water with CO_2. This observation is consistent with the velocity changes predicted by Gassmann's relationship, which has been validated through independent rock physical property testing.

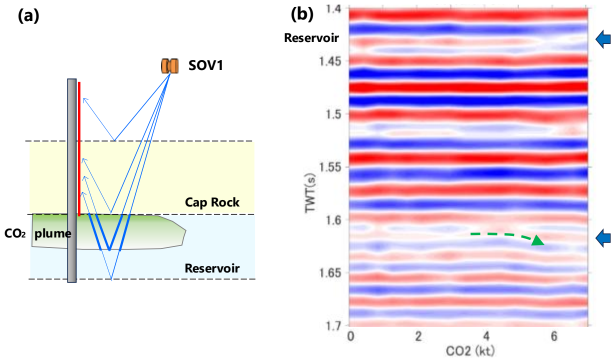

Figure 4: (a) Schematic of CO_2 plume imaging via SOV-DAS; (b) Processed seismic waveform showing time-delay characteristics correlating with cumulative CO_2 injection.

Integration of Monitoring Data and Reservoir Simulation

To validate the observed seismic changes, we compared the monitoring results with numerical simulations of CO_2 behavior. Given the early stage of injection, a horizontal multi-layer model was adopted. Formation flow properties were characterized using porosity and permeability profiles derived from well-log data, with the model discretized into 2-meter layers. The simulation also accounted for wellbore hydraulics, using actual injection rates as boundary conditions at the grid block corresponding to the reservoir top. Numerical simulations were performed using the TOUGH2 code.

Figure 5 presents cross-sectional snapshots of the CO_2 saturation at various cumulative injection stages. The vertical axis represents depth (1,950m to 2,040m, covering the 90m-thick reservoir), while the horizontal axis represents radial distance from the injection well. The simulation results indicate that CO_2 is sequestered primarily within the upper 40 meters of the reservoir. This localized injection interval was subsequently validated by pulsed neutron logging data acquired approximately one year after the commencement of injection.

Synthesis and Implications

The interpretation of the monitoring data indicates that the seismic phase delay observed via SOV monitoring directly correlates with the vertical thickness of the CO_2 plume. A key advantage of the SOV system is its high-frequency acquisition capability, which enabled the detection of subtle seismic changes even during the early stages of injection, with cumulative volumes as low as several thousand tons.

The ability to delineate the CO_2 plume during the initial injection phase provides critical data for assessing reservoir performance. Specifically, this confirms whether the reservoir possesses the requisite injection capacity and containment integrity for the long-term operational lifecycle of the CCS project.

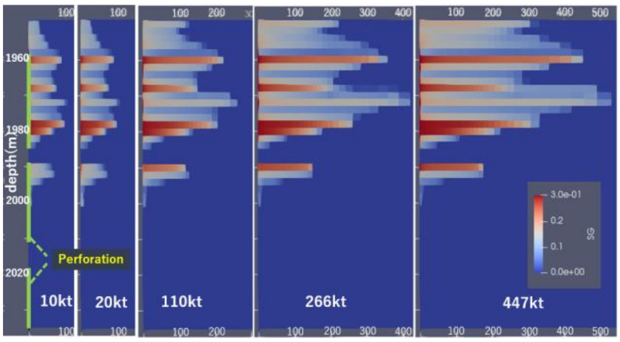

Figure 5: Numerical simulation of CO_2 saturation and plume migration across various injection stages, showing vertical distribution within the reservoir.

DTS Monitoring Results: Thermal Profile Analysis

Finally, we present the Distributed Temperature Sensing (DTS) results obtained at the North Dakota site. Figure 6 illustrates the temperature profile over approximately one year for both the shallow CO_2 pipeline section and the deeper injection well section.

In the pipeline section, long-period cyclic temperature fluctuations are evident, which correlate directly with annual ambient temperature variations at the surface. In contrast, the injection well section exhibits a standard geothermal gradient prior to the commencement of CO_2 injection—characterized by a steady temperature increase with depth. Upon injection, a significant temperature drop is observed, corresponding to the movement of CO_2 (at approximately 15°C) through the wellbore. During intermittent injection pauses (indicated by the brief red segments in Figure 6), the wellbore temperature gradually recovers toward the ambient formation temperature, only to drop again immediately upon the resumption of injection.

Operational Implications

These results demonstrate that DTS provides an effective means for the continuous, real-time monitoring of thermal fluctuations across the entire length of the pipeline and injection well infrastructure. Beyond routine monitoring, this capability serves as a critical diagnostic tool; in the event of an operational malfunction—such as a leak or integrity failure—along the fiber-equipped wells or pipelines, DTS enables the precise, real-time localization of the incident. This spatial accuracy is essential for minimizing response times and ensuring the long-term containment integrity of the CCS project.

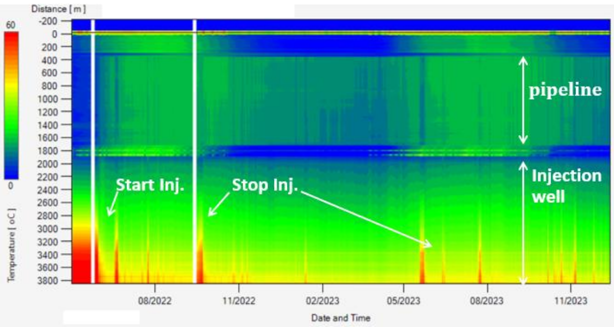

Figure 6: DTS temperature profiles over one year, illustrating seasonal temperature cycles in the pipeline and the localized cooling effect during CO_2 injection within the wellbore.

2.1.3. Field Demonstrations at Australian Sites

In Australia, we are conducting field trials to develop technologies for assessing fault stability during fluid injection and evaluating potential leakage from fault zones. Because geological faults and fractures represent critical leakage risks for CO_2 storage, fiber-optic multi-sensing is being deployed as a primary monitoring tool. Since 2021, we have collaborated with Australian research institutions—specifically those with access to well-characterized fault sites—to establish robust methodologies for fault integrity and stability assessment.

Otway Site (Victoria): Shallow Fault Leakage Detection

At the Otway site, managed by the Cooperative Research Centre for Greenhouse Gas Technologies (CO2CRC), we are conducting tests to detect CO_2 leakage from shallow faults. The experiment involved injecting CO_2 at a depth of approximately 100 meters to simulate leakage from a fault zone. RITE installed high-sensitivity Distributed Strain Sensing (DSS) fibers in newly drilled wells to monitor the subsurface strain during these leakage tests.

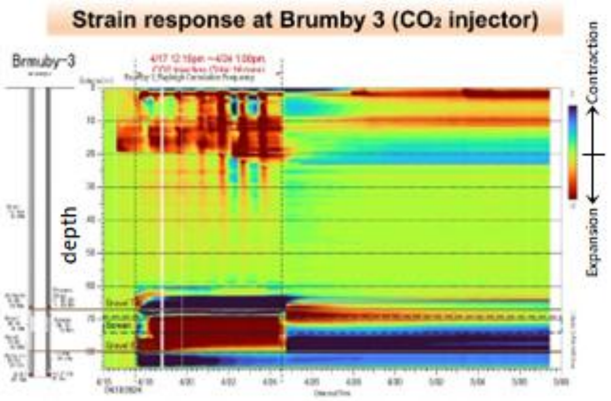

Figure 7: High-sensitivity DSS monitoring results during the shallow leakage test, confirming the absence of CO_2 migration toward the observation well via the fault zone.

Figure 7 indicates the absence of strain anomalies between the 60m and 20m depth intervals, demonstrating that the injected CO_2 did not migrate into the vicinity of the observation well. Given that our established empirical data from domestic sites confirm that fiber-optic sensors can detect minute pressure variations (or fluid movement) within a 15-meter radius, we conclude that the fault fracture zone is not currently acting as a leakage pathway. Future work will involve a comparative analysis with seismic survey data obtained by partner institutions.

Perth South Site (Western Australia): Deep Fault Stability Assessment

In collaboration with the Commonwealth Scientific and Industrial Research Organisation (CSIRO), we are conducting field tests south of Perth to assess the stability of deep-seated faults. This site features a significant fault zone with a fracture width of several hundred meters, through which two research boreholes have been drilled (Figure 8).

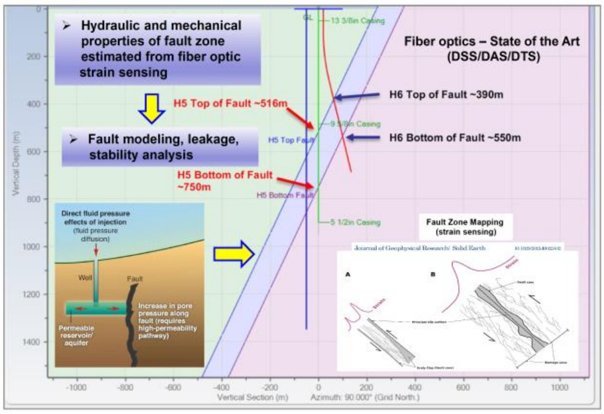

Figure 8: Geological cross-section of the Perth site, showing the intersection of injection and observation wells with a large-scale deep fault zone targeted for stability assessment.

As illustrated in Figure 8, the target fault is identified as the light purple band. Based on core analysis and well-logging data, multiple injection zones (orange triangles) were strategically positioned where the injection wells (green lines) intersect the fault. Observation wells (red lines) are equipped with fiber-optic strain sensors. Four seismometers have also been deployed; observational data over the past four years indicate no seismic activity associated with natural fault movement.

Our future objectives include:

-Simultaneous Monitoring: Executing continuous, integrated strain measurements and seismic monitoring during fluid injection.

-Fluid Behavior Mapping: Using fiber-optic strain data to track fluid movement within the fracture zone.

-Technique Validation: Establishing definitive methodologies for assessing both fault stability (mitigating induced seismicity) and fault integrity (preventing CO_2 leakage through fracture zones).

2.2. Development of a CCS Scenario Generator: Analyzing Long-term Shifts in Major CO_2 Emission Sources

Effective deployment of CCS operations relies heavily on the optimal matching of industrial CO_2 emission sources with suitable geological storage reservoirs. To support this strategic alignment, RITE has been spearheading the development of a comprehensive CO_2 Emission Source Database.

Given that CCS deployment is a multi-decadal endeavor, it is essential to forecast the time-series evolution of emission sources. To address this, we have initiated the development of a "Scenario Generator," a modeling tool designed to analyze the long-term impact and deployment pathways of CCS technologies as part of broader CO_2 reduction strategies.

The following section outlines the current status and utilization of the CO_2 Emission Source Database, followed by an overview of the development progress and future roadmap for the CCS Scenario Generator.

2.2.1. Overview of the CO_2 Emission Source Database

The CO_2 Emission Source Database (hereinafter "Emission Source DB") is designed to facilitate the optimal matching of CO_2 emission sources with suitable geological storage reservoirs. This section outlines the database's data structure, functional capabilities, and current applications.

① **Data Structure**

The database leverages public data from the Ministry of the Environment's "Mandatory Greenhouse Gas Accounting, Reporting, and Publication System (SHK system)" (based on the Act on Promotion of Global Warming Countermeasures). While the system contains approximately 16,000 entries in total, the Emission Source

DB specifically utilizes a refined set of approximately 10,000 thermal power plants and industrial facilities. This data has been processed to support CCS-specific decarbonization analysis as follows:

- Estimation of Direct CO_2 Emissions: Emissions reported under the Act include indirect emissions from electricity and heat supplied by third parties. As CCS technology captures direct emissions at the source, we have derived "direct emission factors" for various industrial sectors through statistical processing. These factors are applied to the reported data to isolate and calculate direct CO_2 emissions for each facility.
- Integration of Biomass-Derived CO_2: Since the original Act-based data focuses on fossil fuel emissions, it excludes biomass sources. To account for Bioenergy with CCS (BECCS)-a key component for achieving negative emissions-we have incorporated estimated CO_2 emissions from biomass fuels, sourced from the Agency for Natural Resources and Energy's electricity survey statistics.
- Storage Potential Integration: The database incorporates the storage potential map from RITE's nationwide survey, "CO_2 Storage Potential Assessment in Japan" (RITE, 2006).

② Mapping and Screening Functions

Emission Source and Reservoir Mapping: Visualizing the spatial relationship between emission sources and storage reservoirs is critical for project planning. The database includes a mapping function that allows for immediate identification of regional disparities—such as the concentration of emission sources along the Pacific coast versus the prevalence of potential storage sites on the Sea of Japan side.

Information Screening: The interface supports dynamic map manipulation, including panning and zooming. Users can select specific regions to extract clustered emission source data, which is highly beneficial for hub-and-spoke infrastructure planning.

Flexible Emission Visualization: CO_2 emissions can be filtered by three categories: fossil fuel, biomass, and total emissions. Figure 9 displays a map of total emissions, while Figure 10 enables a shift to biomass-only visualization, facilitating the strategic evaluation of BECCS-based carbon offset strategies.

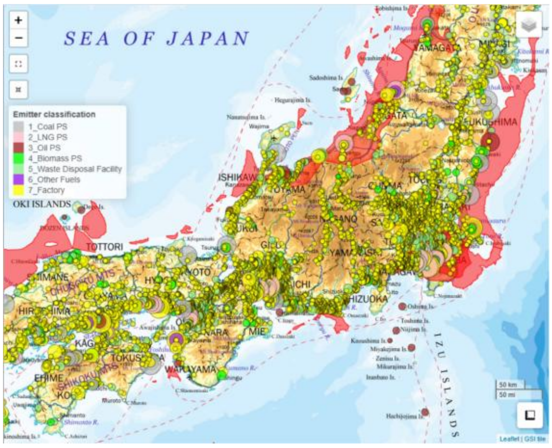

Figure 9: Spatial mapping of major CO_2 emission sources and potential geological storage sites across Japan, integrated into the CO_2 Emission Source Database.

Figure 10: Filtered database visualization focusing on biomass-derived CO_2 sources for the evaluation of negative emission strategies through BECCS.

③ Utilization Status of the CO_2 Emission Source DB

Since November 2024, the CO_2 Emission Source Database has been made available to authorized trial users (for further details, please visit: https://www.co2choryu-kumiai.or.jp/research-theme/post-1140/).

As of March 31, 2026, the database has been adopted by over 100 companies and research institutions. We maintain a proactive engagement strategy with these stakeholders, actively soliciting feedback to iteratively refine and enhance the database's functionality. The widespread adoption and valuable user insights have underscored the strategic importance of this tool, with significant interest and anticipation currently directed toward the development of the "CCS Scenario Generator" introduced in the following section.

2.2.2. Development of a CCS Scenario Generator

Achieving carbon neutrality by 2050 requires rigorous decarbonization strategies across all industrial levels-from entire sectors to individual business sites. CCS is a vital component of this transition; however, its scale and implementation pathway depend on numerous external variables, including energy demand forecasts and the deployment rates of alternative technologies such as electrification and hydrogen-based manufacturing. Given the long development lead times and substantial capital requirements inherent in CCS infrastructure, long-term strategic planning is essential. To support these complex decision-making processes, RITE has initiated the development of a "Scenario Generator" by extending the existing Emission Source DB. This section details an example of scenario setting and the underlying conceptual framework of the generator.

① **Scenario Setting and Long-term Dynamic Estimation)**

a) Analysis Period: The Scenario Generator covers the transition period toward the 2050 carbon neutrality goal, with specific data snapshots modeled for the intermediate milestones of 2030 and 2040.

b) Filtering Criteria for CO_2 Emission Sources: The comprehensive Emission Source DB includes approximately 10,000 data points. To maintain analytical efficiency without sacrificing accuracy, we have restricted the scope of our long-term modeling to thermal power plants and industrial facilities with annual CO_2 emissions exceeding 100,000 tons. This filter narrows the focus to approximately 250 key emitters, which collectively account for over 90% of total industrial CO_2 emissions, allowing for a precise and manageable projection of long-term emission dynamics.

c) Methodology for Emission and CCS Processing Estimation: Projections for 2030, 2040, and 2050 were calculated based on the following framework:

1) Target Achievement: All facilities with annual emissions ≥ 100,000 tons are assumed to reach carbon neutrality by 2050.
2) Facility Lifecycle Integration: Incorporates publicly announced data on the construction, suspension, and decommissioning of power plants and industrial facilities.
3) Industry Alignment: Estimates are grounded in the decarbonization roadmaps published by various industrial associations.
4) Data Interpolation: Where time-series information is unavailable, data is supplemented through RITE's proprietary assumptions and models.

d) Visualization of Projections: Figure 11 displays the estimated 2050 CO_2 emission and CCS processing volumes.

- Spatial Mapping: Light blue circles signify the locations of emission sources and their respective CO_2 capture volumes. Note that sources transitioning to alternative decarbonization pathways (e.g., fuel switching) are excluded from these plots. Dark blue dots represent smaller emitters (< 100,000 t/year), whose spatial distribution remains a critical focus for future decarbonization policy planning.

-Sectoral Breakdown: The graph at the bottom of Figure 11 illustrates the projected CO_2 capture volume by industry. For instance, in the blast furnace steelmaking sector (yellow band in Figure 11), while baseline emissions in FY2022 were approximately 130 million tons, the model projects that 50 million tons per year will remain to be managed via CCS by 2050, accounting for the adoption of electrification, hydrogen-reduction processes, and facility decommissioning.

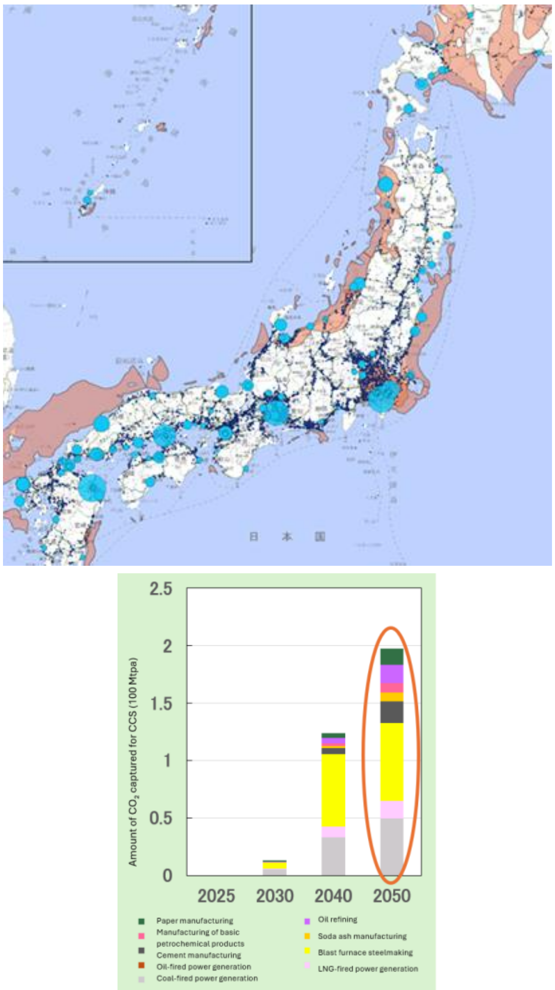

Figure 11: Future projection of CO_2 capture and CCS volumes by industrial sector for 2050, showing the spatial redistribution of emission clusters.

② Development Roadmap for the CCS Scenario Generator

As demonstrated, visualizing the spatial distribution and scale of 2050 CO_2 emission sources alongside potential storage sites (depicted in pale red) provides a robust foundation for evaluating future CCS value chains. However, as this represents only a single hypothetical scenario, it is insufficient for comprehensive strategic planning. In practice, stakeholders must deliberate across a wide spectrum of scenarios-integrating feasibility assessments of competing decarbonization technologies-to identify and optimize CCS value chains.

The CCS Scenario Generator is designed to serve as an integrated decision-making platform to support this collaborative process. Its functional workflow is illustrated in Figure 12:

-Scenario Setter: Enables the definition of diverse, multi-variable scenarios. This module incorporates long-term projections for CCS implementation, fuel switching trends, storage site development progress, and the technological maturity of alternative decarbonization solutions.

-CCS Model Creator: Determines the optimal CCS value chain for each scenario. By integrating CO_2 capture data with geographic variables, this module selects the most efficient CO_2 transport and infrastructure configurations. CCS Model Creator could also be regarded as CCS Value Chain Creator.

-CCS Feasibility Assessment Simulator: Conducts economic and operational feasibility evaluations. This module considers configuration costs, infrastructure requirements, and the impact of economic incentives (e.g., carbon pricing or subsidies) on the overall project viability.

While the current framework remains at the conceptual stage, RITE intends to engage with a broad range of stakeholders to refine detailed technical specifications and accelerate the development of this platform.

Concluding Remarks

The widespread deployment of CCS is a long-term undertaking defined by significant uncertainties. It requires iterative analysis and consensus-building among industry, government, and technical stakeholders. We believe the CCS Scenario Generator will serve as a critical decision-making platform, providing the rapid, data-driven support necessary to navigate these complexities and ensure the successful planning and implementation of CCS initiatives.

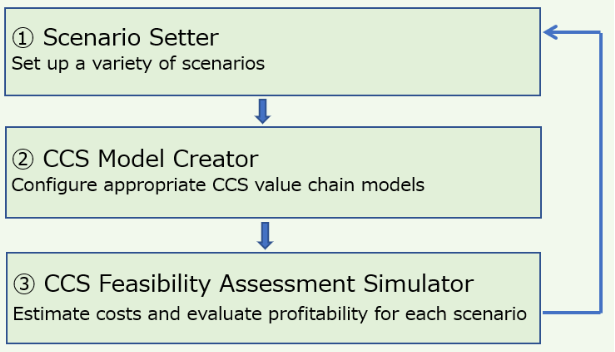

Figure 12: Integrated workflow of the CCS Scenario Generator, incorporating the Scenario Setter, CCS Model Creator, and Feasibility Assessment Simulator.

2.3. International CCS Trends

RITE is actively engaged in international cooperation to address the financial support scheme and technical challenges associated with the global deployment of CCS. By participating in international CCUS forums and forums of global organizations, we monitor emerging trends and actively disseminate information regarding Japan's initiatives. Furthermore, through interviewing in meetings with CCUS related organizations and rigorous literature reviews, RITE investigates and analyzes global CCS projects and governmental support frameworks, utilizing these insights to inform the development of Japan’s domestic CCS regulatory and business environment.

This section highlights key trends in major regions, focusing on operational and planned projects in Europe, North America, and Australia, with particular emphasis on the recent rise of cross-border CO_2 transport.

2.3.1. Developments in Europe

European CCS deployment is underpinned by Directive 2009/31/EC (the CCS Directive), which has provided a unified legislative framework for member states since 2009. The North Sea region serves as the primary hub for large-scale storage resources, with projects advancing rapidly in the UK, Norway, Denmark, and the Netherlands. The European landscape is increasingly defined by cross-border transport projects and cost-effective "hub-and-cluster" industrial configurations. Beyond the North Sea, smaller-scale storage initiatives are currently under evaluation and prepared across the Mediterranean and various onshore locations.

Table 2 Projects that the CEF-E Foundation is considering as candidates for support

Project Name	Location of emission sources	Storage area (accumulation area)
CO_2 Transports	Netherlands, Belgium	North Sea off the coast of the Netherlands, etc.
Aramis	Netherlands, Germany, France, Belgium	North Sea off the coast of the Netherlands
Bifrost	Denmark, Germany, Poland	North Sea off the coast of Denmark
Callisto	France, Italy	Mediterranean Sea off the coast of Italy
CCS Baltic Consortium※	Latvia, Lithuania	(Lithuania, Baltic Sea coast)
Delta Rhine Corridor	The Ruhr region of Germany and the Rotterdam region of the Netherlands	North Sea off the coast of the Netherlands
EU2NSEA	Belgium, Germany, Denmark, France, Latvia, Netherlands, Poland, Sweden, and others	North Sea off the coast of Norway
Norne	Denmark, Sweden, Belgium, UK	Danish land area, North Sea off the coast of Denmark
Prinos-Apollo CO_2	Greece, Bulgaria, Croatia, Cyprus, Italy, Slovenia	Mediterranean Sea off the coast of Greece
Pycasso	France, Spain	Southwestern France
BaltiCO$_2$Net	Denmark, Germany, Latvia, Poland, Sweden	Danish land area
ECO$_2$CEE※	Poland, Lithuania	(Poland (Ports along the Baltic Sea)
Northern Lights	Belgium, Germany, Ireland, France, Sweden, and others	North Sea off the coast of Norway
Nautilus CCS	France, Germany, Norway	(English Channel coastal ports, North Sea coastal ports)
Atlas	Within the EU	North Sea off the coast of Norway
Ship Connect	Belgium (Zeebrugge)	North Sea off the coast of UK
German Carbon Transport Grid	Germany	Northern Europe

※Projects that do not include CO_2 storage

(1) European Union (EU) Policy and Funding

-Cross-Border Infrastructure: To accelerate the deployment of transboundary CO_2 transport infrastructure, the European Commission announced candidate projects for funding under the Connecting Europe Facility for Energy (CEF-E) in December 2025 (Table 2).

-Innovation Fund: Projects involving high technical complexity receive support from the EU Innovation Fund, which is financed by revenue generated from the EU Emissions Trading System (EU-ETS). In the November 2025 funding round, selected projects included decarbonization initiatives in the cement industry, maritime CO_2 capture, and the production of sustainable fuels (e.g., Sustainable Aviation Fuel (SAF) and ethanol), as well as the development of strategic CO_2 hubs in Greece and Poland.

(2) United Kingdom (UK)

The UK government is aggressively promoting CCS as a cornerstone of its "Net-Zero" strategy, with a strategic focus on job creation and economic growth. The national target is to achieve an annual storage capacity of 20–30 million tons by 2030. To reach this, the government identified four industrial clusters for operational deployment by 2030, announcing a £22 billion support package in the autumn of 2024 allocated to the first two primary clusters. This funding milestone catalyzed a wave of Final Investment Decisions (FID) across transport, storage, and capture projects throughout late 2024 and 2025.

Financial Mechanism: The UK's CCS business model is designed to bridge the gap between the cost of CO_2 reduction and its market value, with the latter pegged to the EU/UK Emissions Trading System (ETS) price. Transportation and storage (T&S) segments operate under a regulated framework where the government reviews and approves necessary capital and operational costs. Capture projects are then reimbursed through a differential model, where the government covers the gap between the project's total costs (including T&S fees) and the market price of carbon.

-Project Spotlight: HyNet Cluster

HyNet cluster is one of the flagship initiatives driving the UK's CCS agenda.

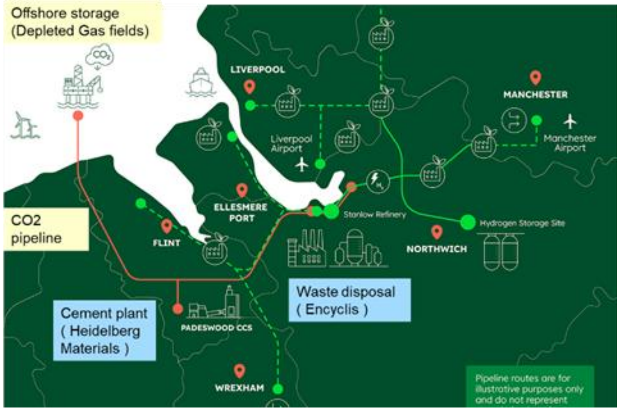

Figure 13: Hynet cluster.

Source: added to padeswoodccs: https://www.mol.co.jp/pr/2026/26013.html

① HyNet cluster T&S Project:

-Operator: Eni (Italian energy major).

-Storage Site: Offshore depleted gas fields (Eni-operated).

-Capacity: 4.5 Mtpa (Phase 1); scaling to 10 Mtpa by the 2030s.Infrastructure: 184 km pipeline network (incorporating 149 km of repurposed existing infrastructure).

-CO_2 Purity Requirements: ≥ 95%.

② HyNet cluster Capture Project:

-Phase 1 (FID Completed): Includes Cement (800 ktpa) and Waste-to-Energy (370 ktpa).

-2030s Expansion Pipeline: Targeting oil refining, hydrogen production, additional waste-to-energy facilities, and Direct Air Capture (DAC) integration.

(3) Norway

Norway occupies a strategic position in the European CCS landscape, leveraging its extensive North Sea oil and gas infrastructure and abundant offshore saline aquifer capacity. With the long-term vision of becoming a primary European storage hub, Norway launched the Longship project to develop a full-scale CCS value chain, which includes the flagship Northern Lights project (Transportation & Storage). This project, supported by significant direct government subsidies, officially commenced operations in August 2025.

① Northern Lights Project

Northern Lights represents a groundbreaking shift toward maritime CO_2 transport, facilitating the injection of CO_2 captured from diverse industrial sources—including the domestic Heidelberg Materials cement plant-into subsea saline aquifers.

-Operators: A Joint Venture (JV) between Equinor, Shell, and TotalEnergies.

-Capture Sources: Multi-national sources across Norway, the Netherlands, Denmark, and Sweden.

-Storage Site: Offshore North Sea saline aquifers.

-Capacity: 1.5 Mtpa (Phase 1); expanding to > 5 Mtpa (Phase 2). CO_2 Purity: ≥99.81 mol% (strict specification for maritime transport safety).

-Funding Structure:

-Phase 1: Direct government subsidy (approx. 14 billion NOK / €1.3 billion) covering both CAPEX and OPEX.

-Phase 2: Backed by the EU's Connecting Europe Facility (CEF-E) fund (€4M for Front-End Engineering Design FEED, €131M for construction).

-Maritime CO_2 Transport Infrastructure Northern Lights pioneered the world's first medium-temperature, medium-pressure (MTMP) liquefied CO_2 carriers for CCS.

-Phase 1 Fleet: Four 7,500 m^3 capacity carriers. K-Line (Kawasaki Kisen Kaisha) has been contracted to operate three of these vessels.

-Phase 2 Expansion: Four additional 12,000 m^3 capacity carriers will be commissioned, with deliveries scheduled to begin in late 2028. These vessels will be owned and operated through a consortium involving K-Line, Malaysian shipping interests, and MOL (Mitsui O.S.K. Lines).

-Manufacturing Profile: Reflecting a strategic global supply chain, six of the total eight vessels are being constructed in China, with the remaining two manufactured in South Korea.

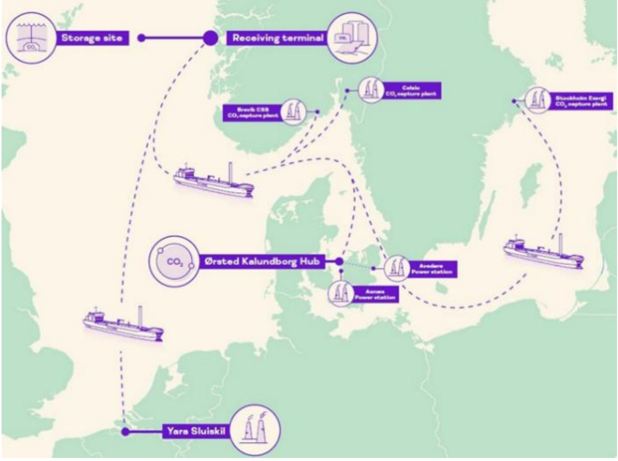

Figure 14: Northen lights project (including transboundary shipping.)

(Source: Added to article on signing a long-term charter contract for two new liquefied CO_2 carriers for Northern Lights)
https://www.mol.co.jp/pr/2026/26013.html

(4) Netherlands

The Netherlands has established a climate target of 49% CO_2 reduction by 2030 (relative to 2019 levels) under its 2019 Climate Act. The national strategy leverages North Sea storage potential to mitigate approximately half of all industrial emissions. Government support is channeled through the SDE++ program, which, similar to the UK model, employs a "Contract for Difference" (CfD) mechanism to bridge the gap between decarbonization costs and the market price of carbon.

① Porthos Project

Porthos represents the EU's first integrated transport and storage hub, with construction initiated in 2024 and operations targeted for 2026.

-Operators: A consortium including the Port of Rotterdam Authority, EBN (state-owned oil & gas), and

Gasunie (state-owned gas grid).

-Storage: Depleted North Sea gas fields; capacity of 2.5 -Mtpa over 15 years.

-Infrastructure: 30 km onshore pipeline + 20 km offshore pipeline. The system is designed for an ultimate capacity of 10 Mtpa, allowing for future integration with the Aramis transport and storage corridor.

-Funding: Secured €100M from the CEF-E fund. Notably, the Port of Rotterdam issued €50M in dedicated "CCS Bonds," with Dai-ichi Life Insurance (Japan) investing €26M.

Figure 15: Infrastructure layout of the Porthos project in the Port of Rotterdam, the EU's first multi-user CO_2 transport and storage hub.
Source: Porthos, Project, https://www.porthosco2.nl/en/project/

② Capture Project

Operators: Shell, ExxonMobil, Air Liquide, and Air Products. Shell's refinery is scheduled for pipeline integration by March 2026, with all capture projects supported by the SDE++ framework.

(5) Denmark

Denmark's 2020 Climate Act targets a 70% GHG reduction by 2030 and full carbon neutrality by 2050. The Danish government actively supports CCS via a cost-value differential subsidy model. While exploration rights for both offshore (2023) and onshore (2024/25) sites have been granted, domestic storage is still transitioning from demonstration to commercial-scale.

① Biomass CCS (BECCS)

This project focuses on CO_2 capture from biomass power plants, with planned maritime export to Norway's Northern Lights storage hub.

Operator: Ørsted.

-Scope: Two biomass plants capturing 430 ktpa.

-Transport: Truck-based transport initially, with plans for future pipeline integration.

-Funding: Commercially bolstered by a carbon removal credit agreement with Microsoft.

② Greensand (Future) Project

Greensand achieved a global milestone in 2023 by completing the first successful cross-border maritime CO_2 transport and offshore injection. The "Greensand Future" commercial phase reached FID in December 2024.

-Operator: INEOS Energy.

-Transport & Storage: Maritime transport of liquefied CO_2 (5,500 m^3 capacity) to North Sea offshore sites. A unique technical feature involves using seawater to reheat the liquefied CO_2 within the vessel prior to injection.

-Funding: Backed by the EU Innovation Fund.

2.3.2. Trends in North America

North America is a global leader in CCS, leveraging abundant fossil fuel resources and a mature industrial base. The region currently operates over 20 active CCS projects, setting the standard for large-scale carbon management.

(1) United States

The U.S. CCS landscape has evolved significantly, built upon a foundation of 4,000 miles of CO_2 pipelines and numerous Enhanced Oil Recovery (EOR) sites developed since the 1970s. The introduction of the 45Q tax credit in 2008 and its subsequent expansions have been the primary catalyst for commercialization, particularly in low-cost capture sectors like ethanol production.

- Policy Update: Following the 2025 administration transition, the scale of tax credits for CCUS was bolstered.

The credit remains at $85 per ton for dedicated geological storage (CCS), while credits for CCU and EOR/EGR have been increased from $60 to $85 per ton. Concurrently, the Department of Energy has initiated rigorous financial audits of existing government-supported projects to ensure fiscal viability, resulting in the termination of support for projects failing to demonstrate expected returns on investment. But information regarding individual projects has not been made public.

① **Net-Zero North Project**

-Operator: Gevo (Biofuel producer; acquired Red Trail Energy’s CCS/ethanol assets in 2025).

-Capture: Ethanol production (biomass-derived), 180 ktpa.

-Storage: Saline aquifer, with RITE collaborating on advanced fiber-optic monitoring trials.

-Funding: A hybrid model utilizing government 45Q tax credits and private sector revenue from the sale of Puro.earth-certified CO_2 removal credits on the voluntary carbon market.

(2) Canada

Canada utilizes a robust mix of carbon pricing (carbon tax) and targeted investment incentives to pursue its carbon-neutrality goals. Large-scale activities are concentrated in Alberta and Saskatchewan.

-Quest Project (Success Story): Since beginning operation in 2015, this project has successfully injected over 9 Mt of CO_2, demonstrating the viability of long-term storage in Western Canada.

-CO_2 Storage Hub Development: The region is pivoting toward storage hubs, with 6 candidate projects near the Edmonton industrial center and 19 others identified across the province.

① **Deep Sky Alpha Project (DAC) & Meadowbrook Storage Hub**

Representing North America's first fully integrated Direct Air Capture and Storage (DACCS) operation (operational since 2025).

-Operator: Deep Sky (Canadian carbon removal developer).

-Capture: Currently 3 ktpa; modular expansion plans target 30 ktpa using 10 diverse DAC systems.

-Storage: Meadowbrook CO_2 Storage Hub (saline aquifer), with a target capacity of 3 Mtpa.

-Funding Structure: * Government Incentives: A 72% aggregate investment tax credit (60% federal CCUS ITC + 12% provincial add-on) and a $5M CAD provincial grant.

-Private Capital: Strategic funding including $40M USD from Bill Gates-backed funds, alongside long-term carbon removal credit purchase agreements with corporate off-takers like Microsoft and the Royal Bank of Canada (RBC).

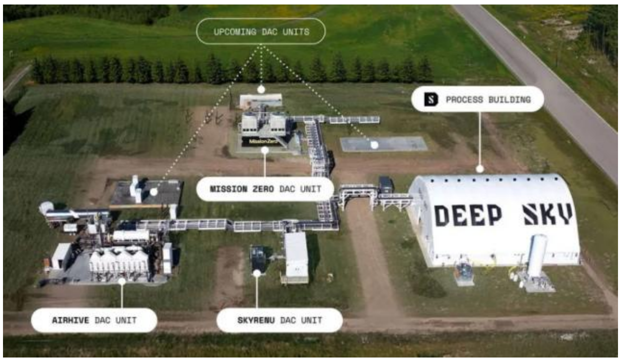

Figure 16: Conceptual framework of the Deep Sky project in Canada, showcasing the integration of multiple Direct Air Capture (DAC) and Ocean Carbon Capture technologies into a unified storage infrastructure.

Source: Deep Sky Alpha: Now Operational
https://www.deepskyclimate.com/alpha

2.3.3. Trends in North Australia

Australia, a global powerhouse in LNG and coal exports, has committed to achieving carbon neutrality by 2050 and a 43% emissions reduction by 2030 (relative to 2005 levels). The government is driving decarbonization across all sectors, including the oil and gas industry, primarily through the "Safeguard Mechanism." This regulatory framework mandates that large-scale emitters (>100,000\$ t-CO_2/year) reduce their emission baselines by approximately 5% annually until 2030. Notably, new natural gas facilities are now subject to mandatory zero-emission requirements, rendering CCS an essential operational necessity. Currently, active projects include Gorgon (injecting into terrestrial saline aquifers) and Moomba (injecting into depleted gas fields). Several large-scale hubs are also in the pipeline, including CarbonNet, Bayu-Undan and Angel.

① Bayu-Undan CCS Project

This project focuses on utilizing depleted gas fields as a regional CO_2 storage hub for both domestic and international emitters.

-Operator: Santos.

- Capture: CO_2 from natural gas processing and overseas sources (e.g., South Korea).

-Storage: Depleted gas fields within East Timorese waters; potential capacity of 10 Mtpa.

-Transportation: Darwin LNG terminal serves as the primary hub, utilizing existing pipelines for offshore transport.

-Regulatory/Financial: Discussions are underway between the Australian and East Timorese governments regarding bilateral agreements for cross-border transport under the London Protocol. Currently, the primary driver is compliance with the Safeguard Mechanism rather than direct government subsidies.

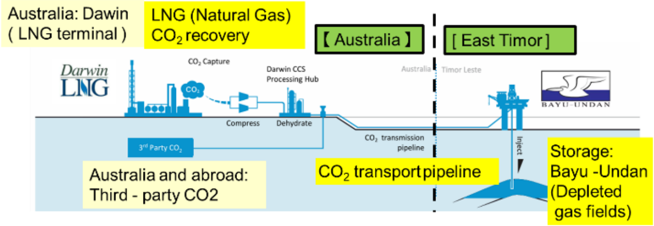

Figure 17: Conceptual model of the Bayu-Undan cross-border CCS project, linking Darwin's industrial hub with offshore storage in East Timorese waters.

Source: Added to Santos - CCUS Project updates.
https://www.env.go.jp/earth/ccs/3rd_speech14.pdf

② CarbonNet Project

A flagship hub initiative spearheaded by the Victoria State government to support the state's 2045 net-zero goal.

-Operator: Victoria State Government.

-Capture: Targeting high-emission industrial clusters, including hydrogen production, fertilizer manufacturing, and biomass processing.

-Storage: Two primary offshore sites:

- Pelican Site: 6 Mtpa for 30 years (saline aquifer).
- Kookaburra Site: 7.5 Mtpa for 20 years (future).

-Transportation: 80 km onshore and 20 km offshore pipeline network.

-Status & Funding:

-FEED phase completed. Total AUD 100M in feasibility funding (AUD 70M Federal, AUD 30M State).

-Fund for business model development, etc. （AUD 2.3M：Global CCS Institute (GCCSI))

-The project has garnered significant international interest, including an MOU between JOGMEC (Japan) and the Victoria State Government.

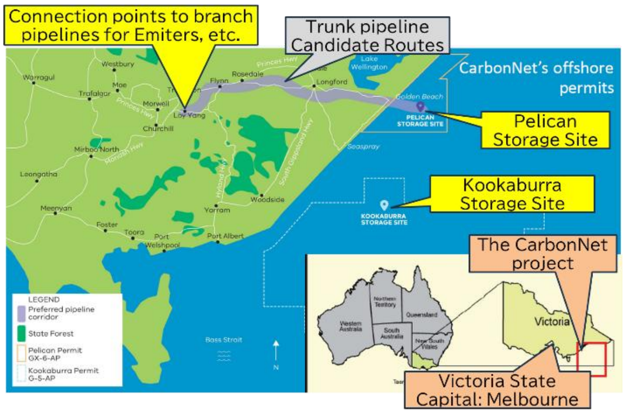

Figure 18: Strategic map of the CarbonNet project, illustrating the connection between industrial sources and offshore saline aquifer storage sites (Pelican and Kookaburra).

Source: Added to the CarbonNet Project
https://gccc.beg.utexas.edu/files/gccc/research/goi/2024/2.02_Bailey_VictoriaGovt_Australia_CarbonNet.pdf
https://hgeo.energy.gov/archives/cslf/sites/default/files/documents/perth2012/Clifford-CarbonNetProject-PIRT-Perth1012.pdf