Report of Tomakomai CCS Demonstration Project at 300 thousand tonnes cumulative injection ("Summary Report")

- Overview -

May 2020

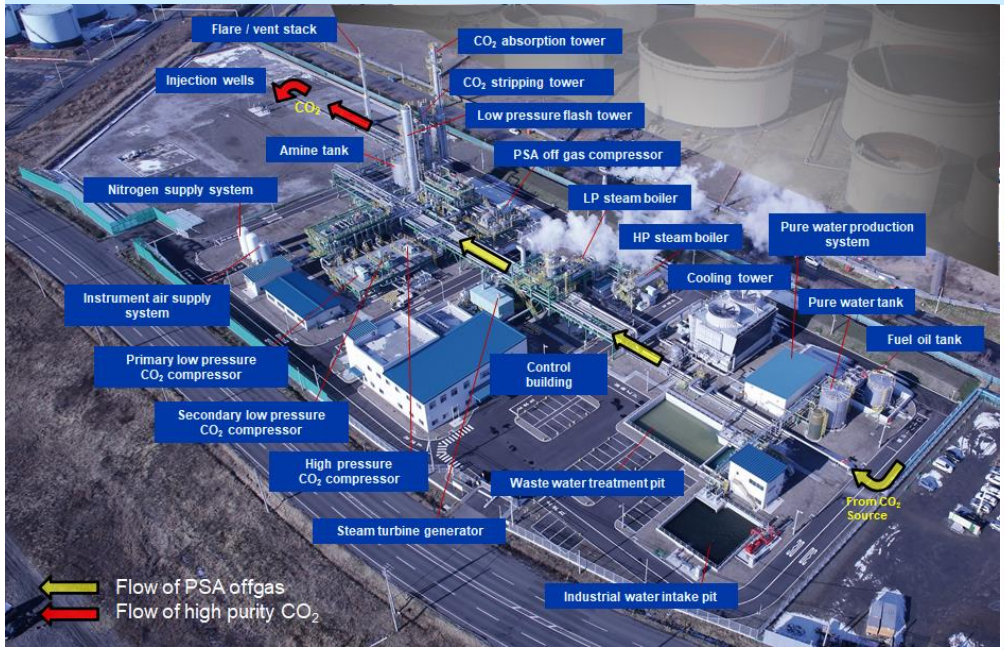
Ministry of Economy, Trade and Industry (METI)

New Energy and Industrial Technology Development Organization (NEDO)

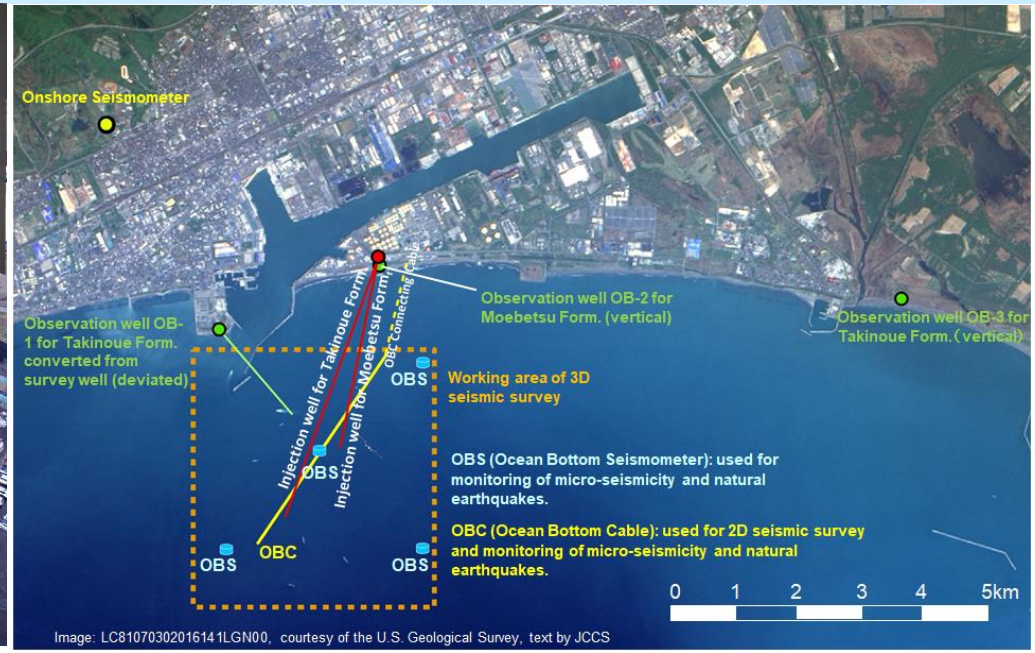
Japan CCS Co., Ltd. (JCCS)

Overview of Tomakomai CCS Demonstration Project

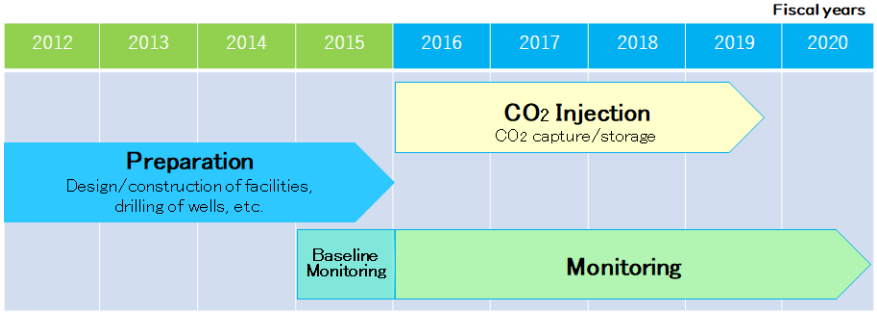
- 1st large scale CCS demonstration in Japan aiming for demonstration at practical scale; conducted by Ministry of Economy, Trade and Industry (METI), New Energy and Industrial Technology Development Organization (NEDO), and Japan CCS Co., Ltd (JCCS). Constructed demonstration facilities from FY2012 to 2015, started injection at scale of 100 thousand tonnes per annum from April 2016, and achieved initial target of 300 thousand tonnes cumulative injection on November 22, 2019.



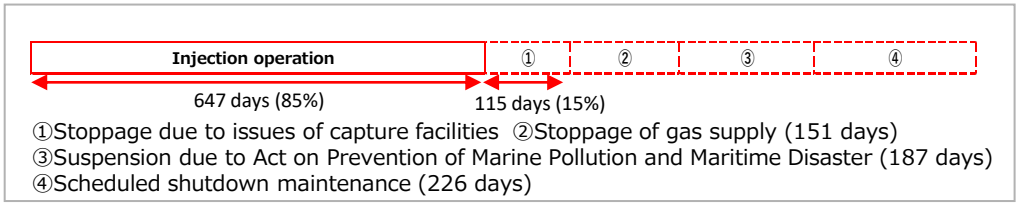
Bird's eye view of capture and injection facilities



Location of monitoring facilities



Tomakomai CCS Demonstration Project – overall schedule



Operational record of Tomakomai CCS Demonstration Project

Tomakomai CCS Demonstration Project Summary Report
Background / Contents

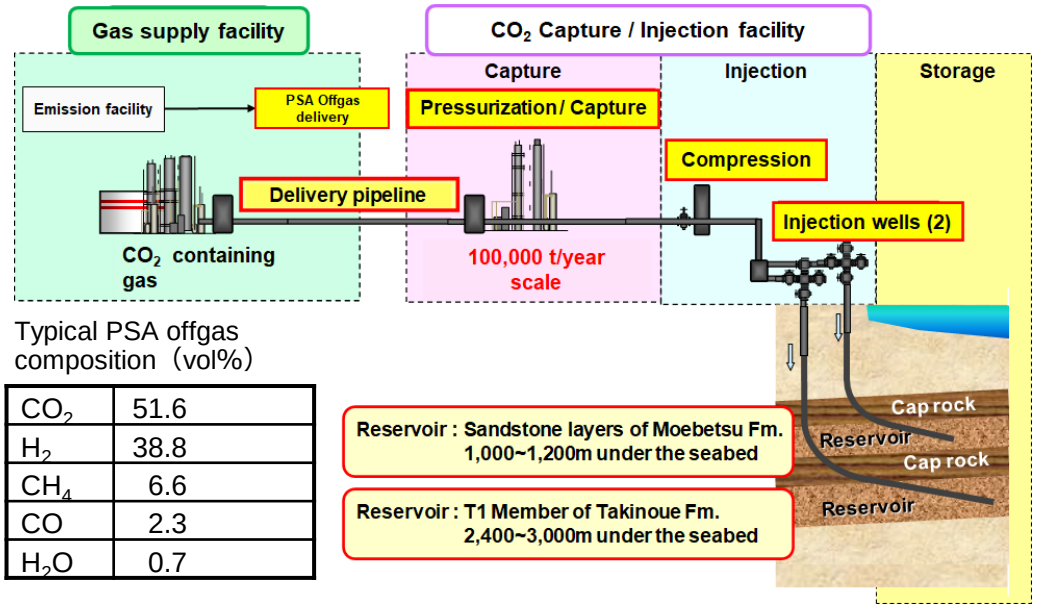
- The “Report of Tomakomai CCS Demonstration Project at 300 thousand tonnes cumulative injection” (“Summary Report”) was compiled taking into account discussion by the JCCS “Review Meeting on the Tomakomai CCS Demonstration Project” and the NEDO “Technical Examination Committee”, comprising experts in mechanical engineering, chemical engineering, geology and geophysics, etc.
- The “Summary Report” summarizes the achievements of the project and issues resulting from the project, etc.

Contents of the “Summary Report”

Overview of Tomakomai CCS Demonstration Project

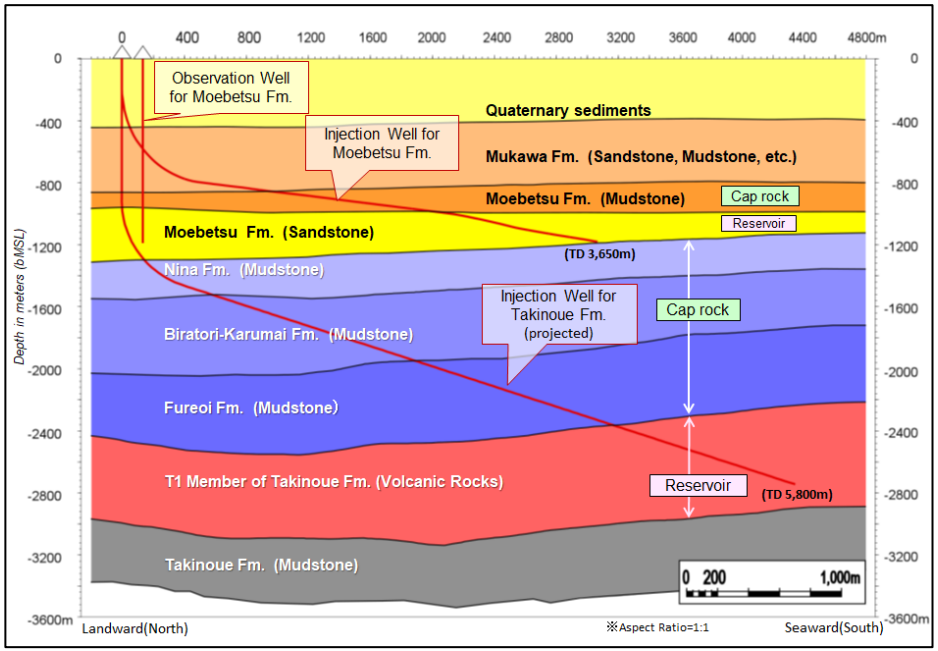
- A portion of the PSA (Pressure Swing Adsorption) offgas containing approximately 52% CO_2 generated by a hydrogen production unit in the Idemitsu Kosan Co., Ltd. Hokkaido Refinery is transported by a 1.4km pipeline to the adjacent capture facilities, where the CO_2 is captured.
- The CO_2 is compressed and stored 3-4km offshore in two sub-seabed reservoirs at different depths – the Moebetsu and Takinoue formations by two independent directional injection wells.

<Overall scheme of Tomakomai CCS Demonstration Project>



Typical PSA offgas composition（vol%）

CO_2	51.6
H_2	38.8
CH_4	6.6
CO	2.3
H_2O	0.7

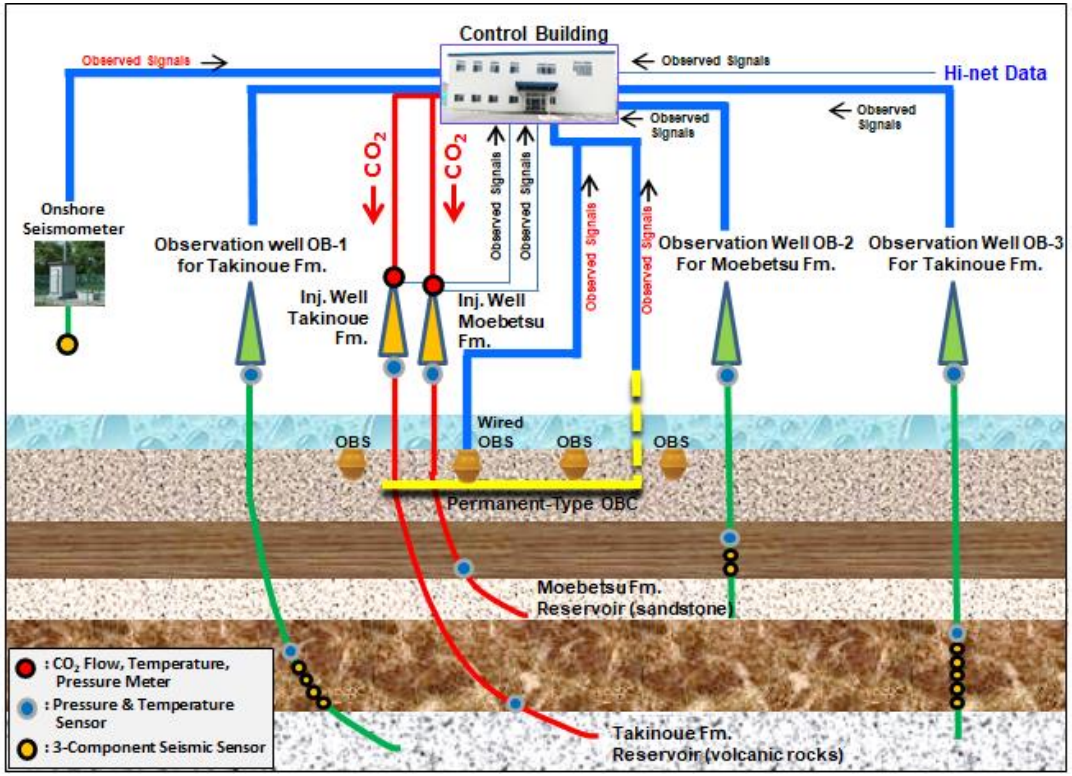


Schematic diagram of geologic layers and injection wells

Overview of Tomakomai CCS Demonstration Project

- Offshore storage of CO_2 in Japan is conducted in accordance with the Act on Prevention of Marine Pollution and Maritime Disaster, with a storage permit issued by the Minister of the Environment. The permit holder (METI in this project) is required to conduct monitoring in accordance with the "Monitoring Plan" submitted in the permit application and confirm that CCS is being conducted safely as planned.
- In accordance with the Tomakomai Project "Monitoring Plan", observation of reservoir temperature and pressure, and seismic surveys to grasp the distribution of CO_2, as well as quarterly (seasonal) marine environmental surveys comprising seawater flow observations, water/sediment sampling to survey seawater, sea-bottom soil, plankton, benthic organisms, and video recording of the sea bottom for benthic organisms and possible existence of bubbles were conducted.

<Schematic diagram of monitoring system>



<Monitored Items>

Equipment/Work	Monitored Items
Injection wells, facilities	Downhole: temperature, pressure Wellhead: injection temperature, pressure, CO_2 injection amount
Observation wells	Downhole: temperature, pressure, micro-seismicity, natural earthquakes
Ocean Bottom Cable (OBC)	Micro-seismicity, natural earthquakes, recording of 2D seismic surveys
Ocean Bottom Seismometers (OBS)	Micro-seismicity, natural earthquakes
Onshore seismometer	Micro-seismicity, natural earthquakes
2D seismic survey	Distribution of CO_2 in reservoir
3D seismic survey	Distribution of CO_2 in reservoir
Marine environmental survey	Marine data (physical, chemical properties, biological habitat, etc.)

Project Objectives and Summary of Results

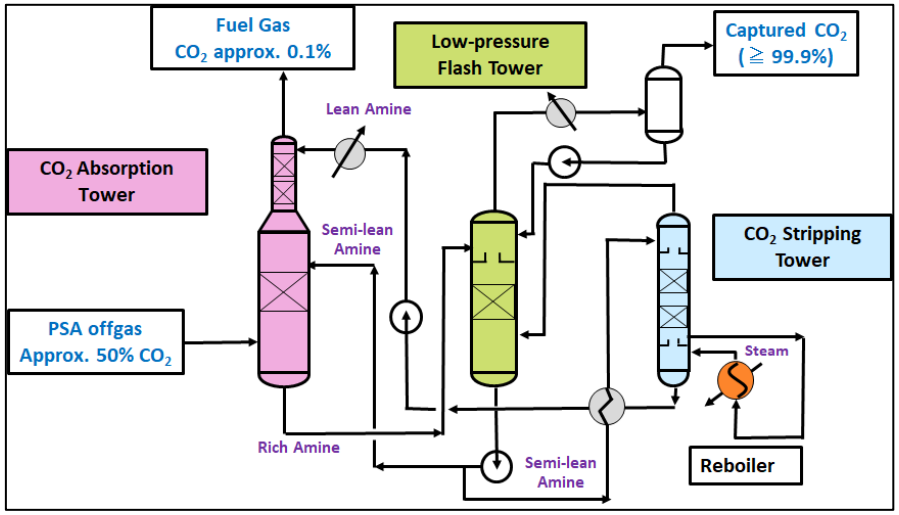
Project Objective	Summary of Results
1) Demonstration of CCS Demonstrate Japan's first full chain integrated CCS system from CO_2 capture to storage with a facility configuration equivalent to a practical project.	Conducted a demonstration of Japan's first fully integrated CCS system, capturing and storing CO_2 from a large-scale emission source (refinery) in accordance with the guideline "For safe operation of a CCS demonstration project", achieving the target of 300 thousand tonnes cumulative CO_2 injection on Nov. 22, 2019. The injection period was 3 years and 8 months, as opposed to the planned 3 years on account of external factors, etc.
2) Demonstration of safety of CCS Demonstrate that CCS is a safe and secure system through sequential operation.	Confirmed that CCS is a safe and secure system through the operation of an integrated CCS system from CO_2 capture to storage, safety and environmental management, various monitoring and marine environmental surveys.
3) Understanding of CCS Widely disclose information on the project through information disclosure and public engagement activities and enhance understanding of CCS.	Information communication activities were carried out continuously in the local community and widely in Japan in order to enhance understanding of the project and public acceptance of CCS. Continuous efforts to communicate project information, collect information and promote international cooperation and collaboration were conducted towards the international community.
4) Practical use of CCS Acquire operational technology as well as strive towards practical implementation.	Acquired operational capability. In addition, findings obtained through the practical application of CCS and remaining issues were summarized.

CO_2 Capture Results

- Achieved following results in capture/injection facilities demonstration: ①Designated capture amount, recovery rate, purity, capture energy; ②Stability of composition, performance of amine solution; ③Complete automation of CO_2 compressor control system (simultaneous injection into two different reservoir types); ④Safe operation of facilities, verification of earthquake-proof design, emergency safety measures for earthquakes.
- Adopted two-stage absorption process employing activated amine for capture process. Achieved capture energy (consumption) target of less than 1.22GJ/t-CO_2; 56% reduction over international project utilizing one-stage absorption (Quest Project separates CO_2 source gas upstream of PSA process of hydrogen production unit, achieving reboiler duty of 2.27GJ/t-CO_2, capture energy of 2.79GJ/t-CO_2 (1)), verifying effectiveness of two-stage absorption process.

(1) Capture energy including electricity consumption estimated from Quest public data (reboiler duty 2.27GJ/t-CO_2)

Energy efficient CO_2 capture flow (two-stage absorption)



Capture energy (consumption) test results

		FY2016	FY2017	FY2019	Designated Value
CO_2 recovery	t/h	25.3	24.3	26.4	25.3
Reboiler duty	GJ/t	0.923	0.882	0.915*1	0.862～0.949*2
Pump electricity	kWh/t	19.8	21.0	18.8	19.2 (EV)
Capture energy*3	**GJ/t-CO_2**	**1.20**	**1.16**	**1.18*1**	**Target:1.22*2**

*1 adjusted value,*2 includes heat loss, *3 capture energy = reboiler duty/boiler efficiency + electricity x heat conversion coefficient/generating efficiency; calculation example for FY2016 capture energy: 0.923/0.9 + 19.8 x 0.0036/0.42 = 1.20 GJ/t-CO_2

Potential deployment of capture technologies of Tomakomai Project

- Capture technologies are largely classified into Pre-Combustion Capture (Pre-CC) and Post-Combustion Capture (PCC) technologies. There is potential to deploy the Pre-CC capture technologies adopted in the Tomakomai Project in facilities with similar operational conditions, such as hydrogen production, ammonia production, and IGCC (Integrated Coal Gasification Combined Cycle).
- There is potential to utilize a large amount of information obtained in this project (capture energy, facility design, operational data, amine consumption, etc.) when considering the economics as well as the basic design of the CCS practical model.

Comparison of operational conditions - Tomakomai / Projects where Tomakomai capture technology could be deployed

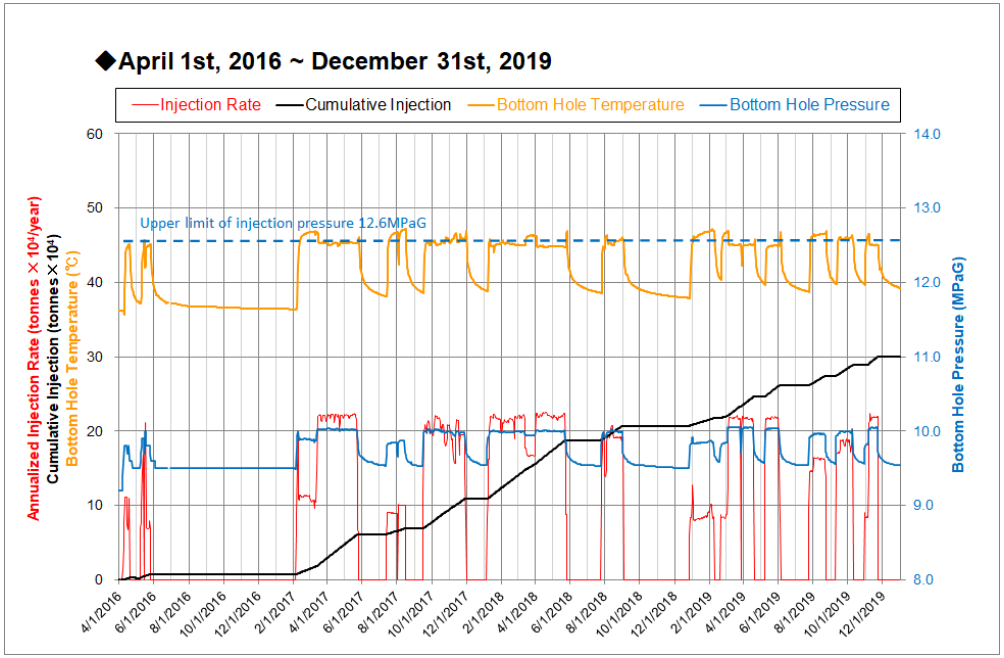
Emission Source		Hydrogen Production	Ammonia Production	IGCC	Hydrogen Production
Gas for CO_2 Capture		NG-SR syngas	NG-SR syngas	Coal gas	PSA offgas
Project Name		Quest	Standard-type	Air-blown FS	Tomakomai
Gas condition					
Gas pressure	MPaA	3.00	2.8	1.51	0.91
CO_2 concentration	mole%	17.00	17.8	23.67	51.60
CO_2 partial pressure	MPaA	0.51	0.49	0.38	0.47
CO_2 concentration at absorber exit	mole%	3.94	0.1	0.03	0.10
CO_2 recovery rate	%	80.0	99.9	99.9	99.9
CO_2 capture method		Activated amine	Activated amine	Activated amine	Activated amine
Amine solution name		Adip-X	OASE	Activated MDEA	OASE

1) PSA offgas used in the Tomakomai project is a flammable reducible gas similar to syngas of hydrogen and ammonia production. These syngases do not contain impurities (oxygen, sulfides, dust, etc.) that would degrade amine. The coal gas generated by the sweet-shift scheme (CO shift after desulfurization) air-blown gasification in IGCC is a reducible gas similar in composition to syngas.
2) The low-pressure PSA offgas of this project was pressurized by a compressor to raise the CO_2 partial pressure to 0.47 MPaA, comparable to other syngases. The CO_2 partial pressure of the post sweet-shift gas (by air-blown gasification) of an IGCC is equivalent to that of this project, and the results of this project could be applied.
3) The capture energy of Tomakomai project was reduced to 1/2～1/3 of existing Pre-CC technologies (one-stage absorption), and significant cost reduction of CCS can be expected.

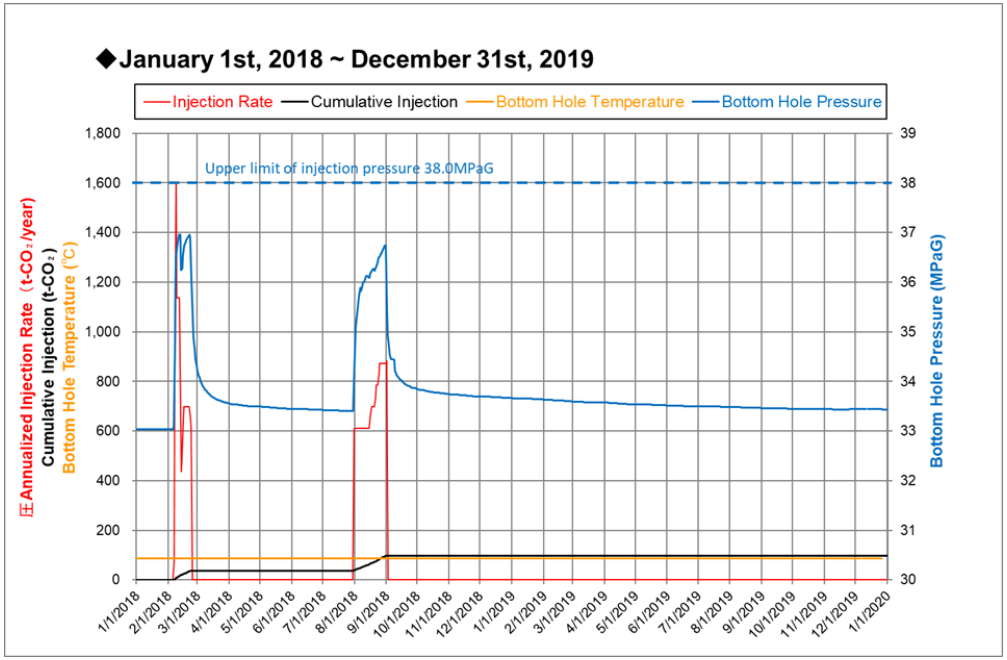
Injection wells and results of injection/storage

- Achieved 300,110 tonnes cumulative CO_2 injection into 2 reservoirs at different depths (Moebetsu Formation – 300,012 tonnes, Takinoue Formation – 98 tonnes).
- The maximum values recorded by the PT sensors (pressure, temperature sensors set close to the reservoir) during injection were sufficiently lower than the upper limits set to avoid destruction of the cap rock of each reservoir. The PT values have remained within normal ranges since the start of injection.
- The injected CO_2 was confirmed to remain within the reservoir, and long-term reservoir simulation predicted that the injected CO_2 would remain in the reservoir 1,000 years after termination of injection.
- Simulation assuming that only the present Moebetsu injection well is used for continuous injection while setting a limit on the CO_2 distribution and pressure rise in the reservoir predicted that 5.73 million tonnes could be injected (P50 model). A volumetric calculation of the storage potential of the entire Moebetsu Formation sandstone body distributed within the same P50 model yielded 486 million tonnes.

＜Injection record of Moebetsu Formation＞



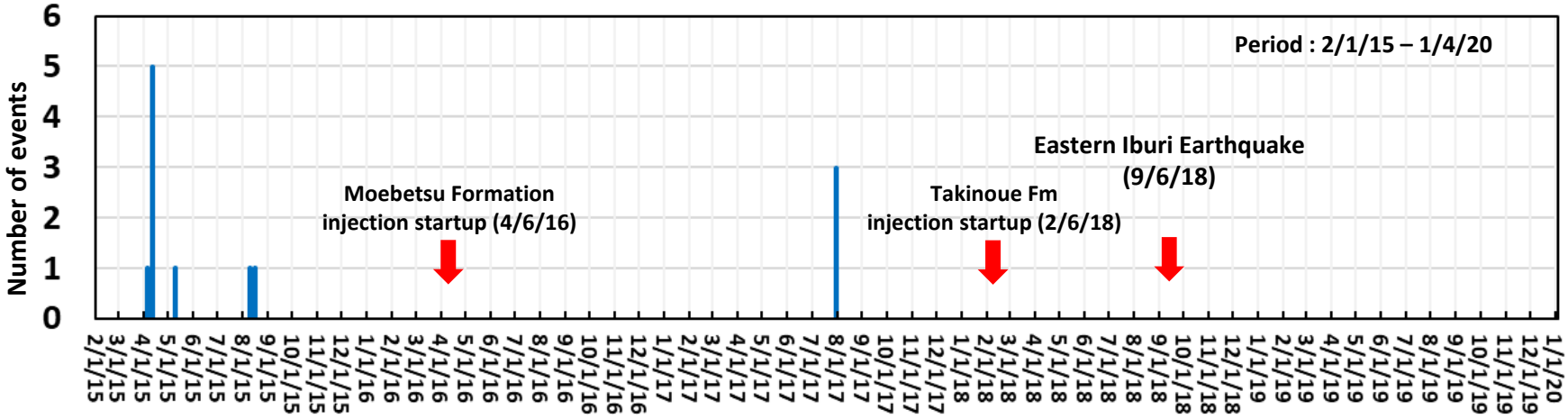
＜Injection record of Takinoue Formation＞



Monitoring Results

- No micro-seismicity or natural earthquakes attributable to CO_2 injection were detected in the vicinity of the injection area between the startup of injection and December 2019, including before and after the 2018 Hokkaido Eastern Iburi Earthquake.
- The distribution of CO_2 in the Moebetsu Formation has been confirmed by seismic surveys since FY2017. The injected CO_2 is limited to the upper portion of the reservoir in correspondence with predictions made in advance, and is not believed to have behaved abnormally, such as leaking outside the reservoir interval.
- The cumulative CO_2 injection into the Takinoue Formation was very small at only 98 tonnes, and the CO_2 distribution could not be confirmed by seismic surveys. The amount is believed to be below the resolution limit of seismic technology.

Histogram of micro-seismic events detected in the micro-seismicity monitoring area

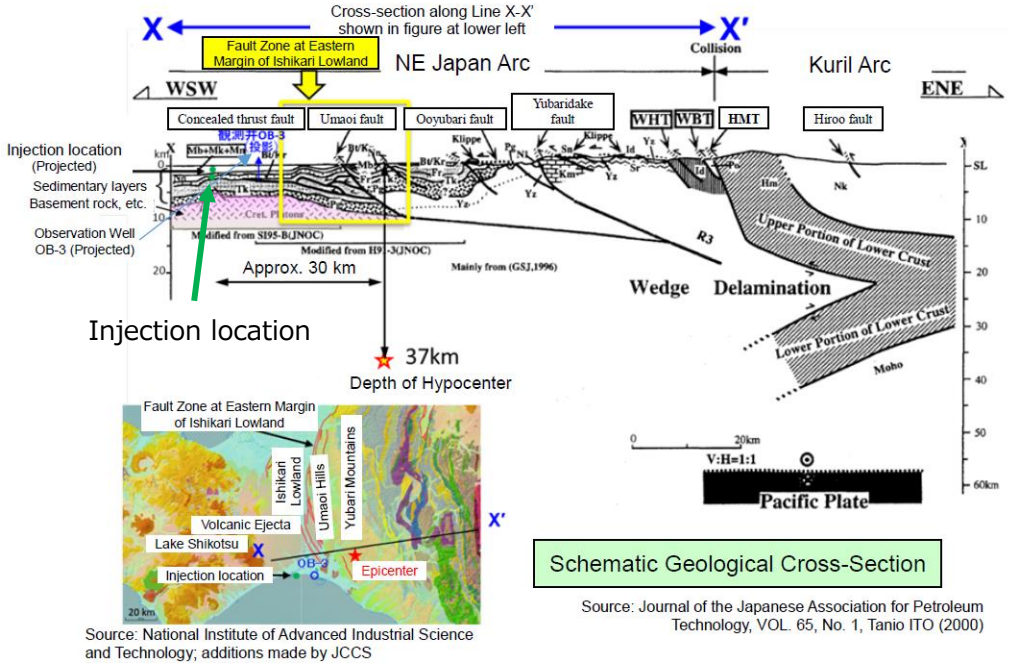


Event detection in the micro-seismicity monitoring area

※ Prior to startup of injection, 9 events were detected, and after startup, 3 events were recorded on Aug. 2, 2017. All events are at depths deeper than 5 km, much deeper than the injection area, and are very small natural earthquakes (micro-seismicity) which can occur in this domain.

2018 Hokkaido Eastern Iburi Earthquake

- At 3:07am Sept. 6, 2018, a magnitude 6.7 earthquake at 37km depth occurred in the central eastern part of Iburi region of Hokkaido. The Tomakomai CCS demonstration site recorded a seismic intensity of lower 5.
- No indication of CO_2 leakage was confirmed in the reservoir pressure and temperature data. Micro-seismic monitoring, which is conducted continuously in the injection area, also did not detect any events (no micro-seismic events have been detected in injection area since startup of injection).
- After the earthquake, CO_2 behavior simulation was conducted on basis of injection record. The stress variation caused by CO_2 injection at the hypocenter of the Eastern Iburi Earthquake was found to be about 1/1,000th of the pressure change in the earth's crust caused by the tidal force of the earth.
- On Oct. 19, 2018, a "Review Meeting on the Tomakomai CCS Demonstration Project" including experts in seismology reached the common understanding that 1) No CO_2 leakage was caused by the earthquake, 2) No data has been confirmed suggesting a connection between the CO_2 storage and the earthquake. A report summarizing the conclusions was posted on the JCCS homepage.

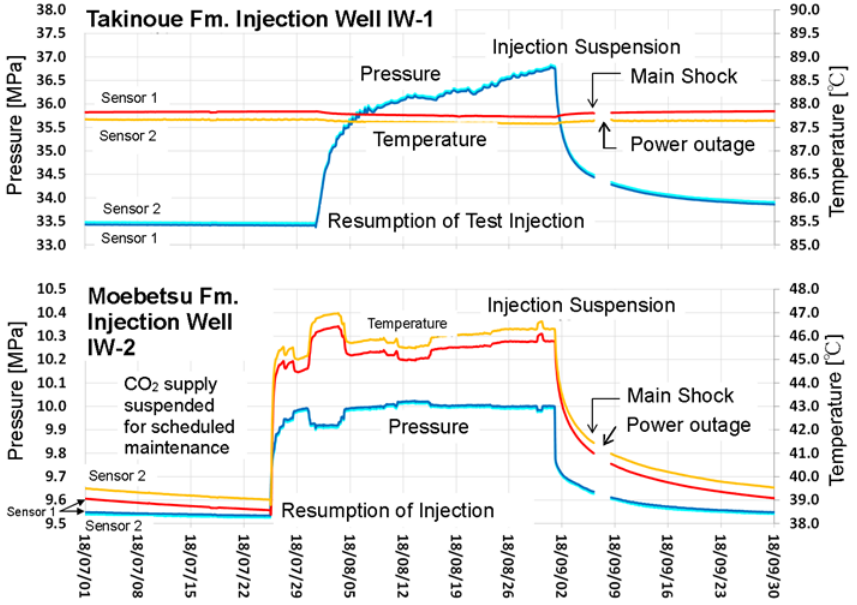


Source: National Institute of Advanced Industrial Science and Technology; additions made by JCCS

Schematic Geological Cross-Section

Source: Journal of the Japanese Association for Petroleum Technology, VOL. 65, No. 1, Tanio ITO (2000)

Schematic cross section of hypocenter and injection location

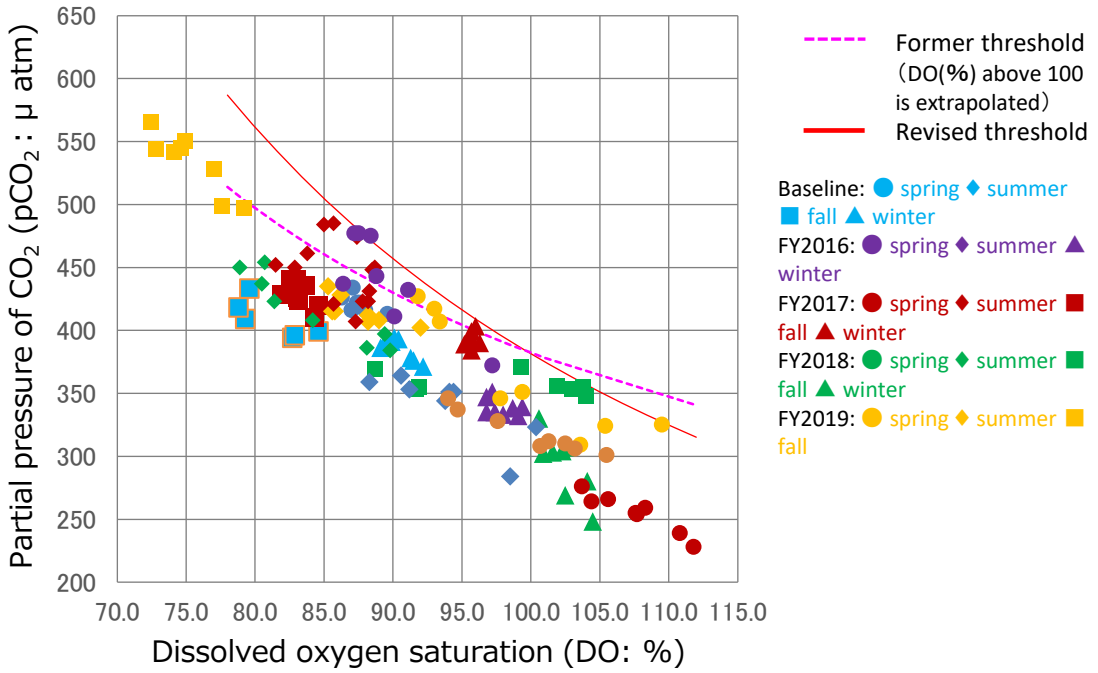


Bottom hole pressures and temperatures of injection wells before/after earthquake (measured by downhole pressure and temperature sensors set close to the reservoir)

Results of Marine Environmental Surveys

- The survey results from FY2016 onwards regarding “Chemical properties of seawater” and “Situation of marine organisms” did not differ greatly with the baseline surveys of FY2013 and 2014, and there were no major trends deviating from those of the baseline surveys.
- Regarding determination of threshold exceedance, the FY2016 spring and FY2017 summer, winter surveys recorded data exceeding the former threshold (derived from baseline survey). Based on the results including confirmation surveys, the Ministry of Environment (MOE) expressed the view that “phenomena indicating CO_2 leakage or the risk thereof were not confirmed” (former threshold curve was derived from only 1 years’ data and insufficient in reflecting natural variations; multiple years’ data was needed)
- No data exceeding the threshold have been observed from FY2018 onwards (From the FY2018 summer survey onwards, threshold exceedance determination is based on revised threshold).

<Threshold of monitoring stage shift and observed values>



Cost Estimation of Practical Model

- On the basis of Tomakomai demonstration data, a cost estimate of a 200-thousand-tonnes/yr scale (scale of Tomakomai project) practical model that could be applied to CCS of hydrogen production, ammonia production and IGCC (Integrated Coal Gasification Combined Cycle) was conducted, as well as a scaled-up 1-million-tonnes/yr practical model.
- The CCS cost of 1-million-tonnes/yr practical model was ¥6,186/t-CO_2 (Captured) and ¥7,261/t-CO_2 (Avoided).

  cf. Scaled-up practical model costs fall in range of published data of Canada Quest Project (Ave. 2016-2018) : 78.92CAD/t-CO_2 (Captured) = ¥6,708/t-CO_2, 99.65CAD/t-CO_2 (Avoided) = ¥8,470/t-CO_2 (85 Yen/CAD and CO_2 Emission factor=0.208)

CAPEX, OPEX of 200-thousand-tonnes/yr practical model (excludes consumption tax)

Breakdown	CAPEX		OPEX		Total	
Cost item	¥/ton	%	¥/ton	%	¥/ton	%
Capture	335	3.0	1,860	16.7	2,195	19.7
Compression	385	3.4	2,174	19.5	2,559	22.9
Common	132	1.2	686	6.2	818	7.4
Injection wells Storage	922	8.3	4,635	41.7	5,557	50.0
Total	1,774	15.9	9,355	84.1	11,129	100.0

※Based on Tomakomai demonstration data, conducted cost estimation of 200-thousand tonnes/yr practical model, and 1-million-tonnes/yr practical model under similar conditions and certain assumptions.

- CO_2 source gas is separated from PSA upstream, and offgas is returned to PSA upstream.
- CO_2 transportation cost is not included. Facility housing, operator labor costs are assumed to be provided by refinery and not included.
- Fuel gas unit cost: ¥1,205/GJ (equivalent to ¥48.2/Nm^3), electricity unit cost: ¥10.84/kWh (excluding consumption tax).
- Captured cost: CCS cost/injected CO_2 amount; Avoided cost: CCS cost/(injected CO_2 amount − CO_2 generated by CCS)

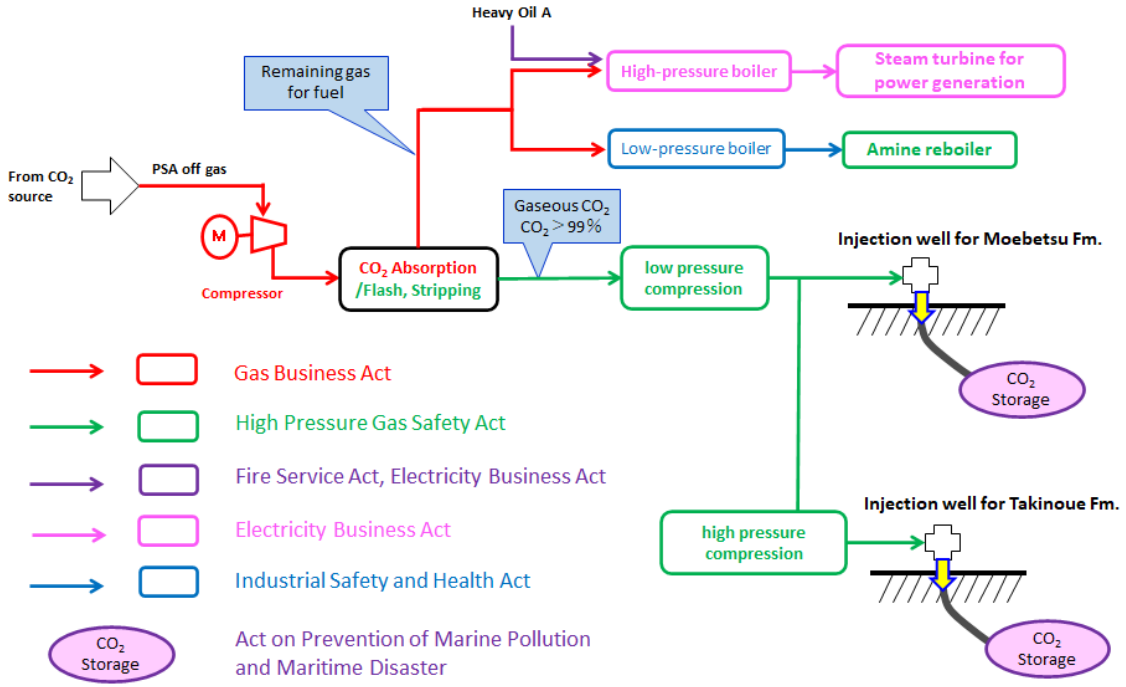
Comparison of costs of 200-thousand-tonnes/yr and 1-million-tonnes/yr Practical Models

CCS Cost (¥/t-CO_2)	200-thousand-ton (Image of practical model)	1-million-ton (Image of practical model)
1) Capture / Injection		
CAPEX	852	590
OPEX	4,720	4,079
Total	5,572	4,669
2) Injection wells / Storage		
CAPEX	922	369
OPEX	4,635	1,148
Total	5,557	1,517
3) Grand Total		
Captured	11,129	6,186
Avoided	13,328	7,261
4) CO_2 emission factor (t-CO_2 emitted from capture/injection facilities) ÷ (t-CO_2 captured/injected)		
t-CO_2/t-CO_2	0.165	0.148

Compliance with laws and regulations & Issues ①

- As Japan has no CCS specific laws, existing laws and regulations governing the operation of the project facilities were applied.
- Regarding the CO_2 capture facilities, the High Pressure Gas Safety Act, Industrial Safety and Health Act and Gas Business Act were applied.
- With regard to the safety standards of the injection / storage facilities and injection operations, compliance was made with the Mining Act and Mining Safety Act (As there were no management standards for CO_2 injection, measures were taken to comply with the METI guideline “For safe operation of a CCS demonstration project” (August 2009), and taking into account international CCS regulations, technical standards and guidelines, a “Reservoir Management Standards Manual During CO_2 Injection” was prepared and applied).
- Regarding sub-seabed dumping (geologic storage) of CO_2, compliance with Act on Prevention of Marine Pollution and Maritime Disaster is required (A “Monitoring Plan” pursuant to the Act was followed).

<Laws applied to surface facilities, CO_2 storage>



Compliance with laws and regulations & Issues ②

Method of CO_2 Concentration Measurement

It was found that there was a difference in the method stipulated by the Ministry of Environment (MOE) ordinance and that adopted widely by third party organizations. Regarding the MOE method, it was pointed out that quick analysis was not possible as an enormous amount of time would be required to establish the analysis conditions, taking into account factors such as changes in carrier gas, preparation of calibration gas, and creation of the calibration curve. As a consequence, METI and MOE discussed the matter, and agreed upon a realistic analysis method virtually equivalent to the MOE ordinance.

Marine environmental surveys

Marine environmental surveys were conducted in accordance with the “Monitoring Plan” pursuant to the Act on Prevention of Marine Pollution and Maritime Disaster. Issues have become apparent such as the possibility that the index currently used to detect possible CO_2 leakage into the sea could generate false positives caused by natural variations rather than actual leakage, and that the effectiveness of surveying the sea-bottom soil and condition of marine organisms as a method of detecting CO_2 leakage is believed to be low. These issues should be taken into account in the application procedure for the next period of the CO_2 storage permit (FY2021～2025), with a view to reduce the current number of survey points, survey frequency, and survey items.

CO_2 Storage

1) Subsurface rights for the drilling of injection wells
   Mining rights are stipulated in the Mining Act. It is necessary to consider whether subsurface access rights should be stipulated regarding the drilling of CO_2 injection wells as well as storage of CO_2.
2) Long term liability regarding the storage location and stored CO_2
   In Japan, the provisions for long term liability and the transfer of such liability have not been established. There is only mention in the Act on Prevention of Marine Pollution and Maritime Disaster that as long as there is storage (dumping) of CO_2 in the subsurface, the implementer shall continue monitoring.

Compliance with laws and regulations & Issues ③

- In countries where CCS projects are being implemented, national and regional government have enacted laws and made advancements in preparing legal and regulatory frameworks for CO_2 storage. Though there is variety in the form of legal framework, almost all jurisdictions have common features such as permitting for exploration, access, storage, management of injection/storage during the injection period, regulations on monitoring, reporting, verification and transfer of liability.
- In addition, preparation of systems such as tax credits and subsidies that could incentivize CCS deployment are being advanced overseas, and likewise preparation in Japan is an issue.

CCS laws and regulations in the world

Country/State	Regulation / Policy Name	Date issued	Regulatory Authority	Jurisdiction
EU	EU CCS Directive	2009	European Committee (EC)	Onshore, Offshore
UK	Energy Act 2008	2008	Oil & Gas Authority (OGA)	Offshore
Netherlands	Mining Act, Mining Decree, Mining Regulation	2011	Ministry of Economic Affairs and Climate Policy	Offshore
Australia ※1	Offshore Petroleum Amendment (Greenhouse Gas Storage) Act 2006	2006	Department of Industry, Science, Energy and Resources	Offshore (＞3 nautical miles)
U.S. ※2	Underground Injection Control (UIC) Program	2010 (amended)	Environmental Protection Agency (EPA)	Onshore
Alberta, CA	Carbon Capture and Storage Statutes Amendment Act, 2010	2010	Ministry of Energy	Onshore
Saskatchewan, CA	Oil and Gas Conservation Regulations, 2012	2012	Ministry of Energy and Resources	Onshore
Japan	Act on Prevention of Marine Pollution and Maritime Disaster	2007	Ministry of Environment (MOE)	Offshore

※1 Onshore and coastal waters (areas less than 3 nautical miles) are administered by state and territory governments. Victoria has established onshore/coastal waters frameworks; South Australia, Queensland have onshore frameworks; West Australia has established regulations for the Gorgon project.

※2 There is not sufficient legal framework for liability during injection period. UIC Class VI establishes framework for CCS wells.

Public Engagement Activities and Issues（Domestic）

- Information communication activities were carried out in Tomakomai City and neighboring areas as well as widely in Japan, measures were implemented for information communication in emergency situations (such as preparing manuals), and efforts were made to build trust with the local community.
- Public awareness of CCS is still very low. Knowledge enhancement activities such as exhibiting in environmental exhibitions and giving lectures in universities should be continued. Where CCS is being carried out in a new area, it is important to have the local community know that the government is responsibly advancing the project, to draw from the knowledge acquired in the Tomakomai project and implement activities that suit the region, and then to build a trusting relationship with the local community.

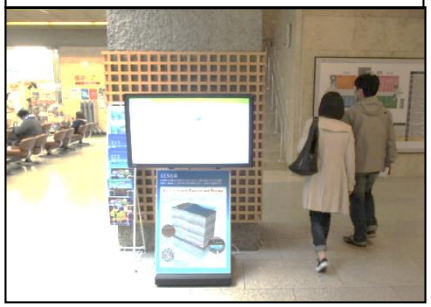
CCS Forum (Tomakomai)

Lab classes for kids

Site tours

Brochures/Manga（Japanese/English）

Information disclosure system in Tomakomai City Hall



Record of Information Communication Activities

FY		Field Trips	Panel exhibits	Booths	Kids' Labs	Univ. Lecture	Presentations	CCS Forums
2012	Number	3	29	0	1	0	0	1
	Attendance	83	—	0	100	0	0	236
2013	Number	19	18	4	10	12	0	1
	Attendance	221	—	2,460	242	536	0	202
2014	Number	44	8	4	3	6	0	1
	Attendance	558	1,160	2,118	89	245	0	369
2015	Number	126	6	4	6	7	19	1
	Attendance	1,570	859	2,827	110	534	1,508	320
2016	Number	153	5	5	1	8	14	1
	Attendance	2,013	688	2,834	24	404	908	312
2017	Number	168	8	6	5	7	12	1
	Attendance	1,944	1,417	4,080	176	313	1,139	315
2018	Number	181	7	7	5	11	10	1
	Attendance	2,276	1,690	4,653	130	1,104	591	368
2019	Number	206	8	11	3	12	15	1
	Attendance	2,168	1,896	7,128	120	724	875	600

International Activities and Future Steps

- The Tomakomai CCS Demonstration Project is a rare project in the world, where the government, private sector and local community joined efforts to steadily achieve results, experienced the world's first occurrence of a major earthquake near the injection area, and continued onwards.
- The Tomakomai demonstration site has received over 1,400 international visitors comprising government officials, national companies, embassies, private companies, CCS research organizations, thinktanks and consortiums, universities, academia, banks and financial organizations, and media.
- In October 2016, the project was recognized by the CSLF (Carbon Sequestration Leadership Forum, a ministerial level initiative to advance CCS technology), and Japan CCS Co., Ltd. (JCCS) was nominated the Asia-Pacific regional champion for stakeholder engagement.
- In October 2019, JCCS and the International CCS Knowledge Centre (Saskatchewan Canada organization advancing CCUS; worldwide contribution by sharing vast knowledge acquired in Boundary Dam Project) signed an MOU for cooperation in CCS to share mutual knowledge to advance the deployment of CCUS in the world.
- A key future objective will be to increase opportunities to gain experience through collaboration, cooperation with international undertakings and deepen our knowledge, and further, to accumulate know-how to overcome issues common to Japan and abroad and alleviate various barriers to CCS through international cooperation.
- The present situation is that discussions regarding legal framework for CCS and conceptual design of business models are more advanced overseas. It is important as well as an effective approach that Japan actively participate in such international discussion and obtain information from various cases on matters such as the role of the public and private sector.

CSLF Recognition of Tomakomai CCS Demonstration Project

Signing of MOU by International CCS Knowledge Centre and JCCS