Tomakomai CCS Demonstration Project of Japan, CO₂ Injection in Process

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Abstract

The Tomakomai CCS demonstration project is currently being undertaken by the Japanese government in Tomakomai City, Hokkaido Prefecture, Japan. The project is scheduled to run between the period of JFY(*) 2012 - 2020 to demonstrate the viability of a full chain CCS system, from CO₂ capture to injection and storage. One hundred thousand tonnes per year or more of CO₂ derived from an industrial source will be injected and stored in saline aquifers under the seabed in the offshore area of Tomakomai Port. CO₂ injection began in April 2016. This paper outlines the demonstration plan and reviews the progress of the project. (*JFY denotes April of calendar year to March of following year)

Keywords: CCS; demonstration; offshore; carbon dioxide; capture; storage; monitoring; Tomakomai

1. Introduction

In February 2012, the Ministry of Economy, Trade and Industry (METI) of Japan officially decided to implement a CCS demonstration project in Tomakomai City, Hokkaido Prefecture, Japan. The preparation work comprising the first four-year period of JFY 2012 - 2015 was commissioned to Japan CCS Co. Ltd. (JCCS) following a formal examining process in April 2012. During this period, all the necessary facilities and systems were prepared and constructed, including onshore CO₂ capture and injection facilities and various onshore and offshore monitoring systems. Baseline data were acquired by the monitoring systems, and two CO₂ injection wells were drilled. Starting from April 2016, the implementation of CO₂ injection is scheduled for three years, and the monitoring of microseismicity, natural earthquakes and the marine environment will be conducted for five years.
2. Project overview

The goal of the project is to demonstrate the viability of a full chain CCS system from capture to injection and storage in saline aquifers on a practical scale, and contribute to the establishment of CCS technology for practical use by around 2020 and future deployment of CCS projects in Japan.

The main characteristics of the demonstration project are as follows:

- First full chain implementation of CCS in a country prone to frequent earthquakes.
- Low energy consumption throughout the CO₂ capture process.
- Application of two highly deviated injection wells drilled from the onshore injection site targeting the most prospective points of two separate reservoirs in the offshore sub-seabed.
- Extensive marine monitoring system for observation of CO₂ behaviour in the reservoirs, micro-seismicity and natural earthquakes.
- World’s-first CCS project reflecting the London Protocol.

The Engineering, Procurement and Construction (EPC) work of the onshore facilities was started in November 2012 and completed in October 2015. The CO₂ source is a hydrogen production unit (HPU) of an oil refinery located in the coastal area of Tomakomai Port. The HPU provides CO₂ rich offgas to the Tomakomai demonstration project CO₂ capture facility via a pipeline 1.4 km in length. In the capture facility, gaseous CO₂ of 99% purity is recovered from the offgas by a commercially proven amine scrubbing process with a design capacity is 200,000 tonnes per year. A two-stage absorption system with a low pressure flash tower was adopted to reduce the amine reboiler duty in the capture system and the total energy consumption for CO₂ capture is expected to be 1.22 GJ/tonne-CO₂ or less in case of a typical feed gas composition.

At the injection facility, the gaseous CO₂ is compressed and injected into two different offshore reservoirs by two dedicated deviated injection wells. The deep reservoir (Takinoue Formation) is located at a depth of approximately 2,500 m below the seabed. This reservoir is a Miocene saline aquifer composed of volcanic and volcaniclastic rocks and is approximately 600 m thick. The shallow reservoir (Moebetsu Formation) is located at a depth of approximately 1,000 m below the seabed. This reservoir is a Lower Quaternary saline aquifer, mainly composed of sand and is approximately 200 m thick.

The storage points are located 3 to 4 km offshore. The deep injection well was drilled with a maximum inclination of 72 degrees, total drilling depth of 5,800 m, vertical depth of 2,753 m and horizontal reach of 4,346 m. The shallow injection well, an extended reach drilling (ERD) well, was drilled with a maximum inclination of 83 degrees, total drill depth of 3,650 m, vertical depth of 1,188 m and horizontal reach of 3,058 m. A perforated liner covered by sand control screens was set over the reservoir interval in order to minimize sand flow back into the well.

In order to confirm the safety and stability of CO₂ injection, it is necessary to set up systems to monitor the behaviour of CO₂ in the reservoirs and detect any CO₂ leakage from the reservoirs. As Japan is highly susceptible to earthquakes, it is also necessary to monitor natural earthquakes and micro-seismicity to verify that natural earthquakes do not impact the stored CO₂ and that CO₂ injection does not cause any perceptible increase in earth tremors.

In Japan, CO₂ geological storage below the seabed is regulated by the Act on Prevention of Marine Pollution and Maritime Disaster, enacted and amended to reflect the London Protocol. A series of marine environmental assessments prior to CO₂ injection was necessary prior to applying for a storage permit to conduct CO₂ injection.

After the installation of the monitoring tools and systems, baseline data acquisition of temperature, pressure of the reservoirs and seismicity monitoring was started at the end of JFY 2014 and finished at the end of JFY 2015. A 2D baseline seismic survey was performed in JFY 2013. Baseline surveys for marine environmental monitoring were conducted each quarter in JFY 2013 and 2014. The monitoring of CO₂ behaviour, natural earthquakes, micro-seismicity and the marine environment will be conducted during CO₂ injection, and for two additional years
following the termination of injection.

Public engagement is of vital importance to the success of CCS projects. Key stakeholders have been engaged since the preparatory stage of the project. From JFY 2011, a wide range of programs have been implemented in Tomakomai and other areas, where we explain CCS technology, provide project information to local residents and various stakeholders. These activities are all carried out with the support of the Tomakomai City government.

3 Facilities

3.1 Ground facilities

The CO2 source is a Pressure Swing Adsorption (PSA) hydrogen production unit of an adjacent oil refinery which supplies offgas containing H2, CH4, CO and a large amount of CO2 (44-59% by volume). This gas is currently used as part of the fuel for the reformer furnace. In the demonstration project, up to 60% of the PSA offgas is transported to the Tomakomai demonstration project CO2 capture facility via a 1.4 km pipeline.

Figure 1 shows the gas flow from the CO2 source to the capture and injection facilities. At the capture facility, gaseous CO2 of 99% purity is recovered from the PSA offgas by an activated amine process at a rate of 100,000 tonnes per year or more. A two-stage absorption system with a low pressure flash tower (Section 3.2) was selected to reduce energy consumption in the capture system. Following CO2 capture, the remaining gas which contains H2, CH4 and CO is utilized as fuel for a high-pressure boiler to supply steam to generate electric power for the capture and injection facilities, and a low-pressure boiler to supply steam to an amine reboiler.

At the injection facility, the gaseous CO2 is injected into two different offshore reservoirs through two dedicated injection wells. The injection pressure of each well is attuned to the individual reservoir conditions, with a low pressure compression system for the shallow reservoir (Moebetsu Formation), and a high pressure system for the deep formation (Takinoue Formation). Centrifugal type compressors have been selected in order to obtain operational data and experience which can be applied in future commercial scale CCS projects. The CO2 injection rate that will be allocated to each reservoir will depend on the operational load of the oil refinery during the injection period as well as the actual reservoir conditions.

Figure 1. Gas flow from CO2 source to capture and injection facilities
The on-site construction of the ground facilities was started in July 2014, completed in late 2015, after which commissioning was conducted. Figure 2 shows an aerial photo of the ground facilities.

### 3.2 CO₂ capture facilities

Figure 3 shows the CO₂ capture process applied to the project. World CCS trends to date indicate that the majority of CO₂ emission sources for CCS projects are natural gas processing facilities with pre-combustion capture and industrial separation that operate at high CO₂ partial pressure. In order to enable the Tomakomai project to obtain operational data and experience which can be applied in future commercial scale CCS projects in line with the mainstream CCS trend, the PSA offgas pressure is increased by a centrifugal compressor to attain a level of CO₂ partial pressure comparable to that employed in natural gas processing, pre-combustion capture and industrial separation.

The CO₂ capture process has been licensed from BASF. The CO₂ capture rate is 25.3 tonnes/h by design. A substantial portion of the CO₂ in the CO₂-rich amine solution from the CO₂ absorption tower is stripped in the low-pressure flash tower by depressurizing and by heating by the steam containing CO₂ stream from the CO₂ stripping tower. The greater part of the semi-lean amine solution from the low-pressure flash tower is recycled to the middle part of the CO₂ absorption tower to capture bulk CO₂ and the remaining smaller part is sent to the CO₂ stripping tower to be regenerated into a CO₂-lean amine solution. In the CO₂ absorption tower, a predominant portion of the CO₂ is captured at the lower part, and the rest is captured at the upper part. This two-stage absorption system with a low-pressure flash tower results in a significant reduction of the amine reboiler duty. The amine reboiler duty was measured as 0.92 GJ/tonne-CO₂ or less for a typical CO₂-containing feed gas (CO₂:52%, H₂:39%, other components:9%), which is around one-half to one-third of a conventional activated amine CO₂ capture process without a low-pressure flash tower or two-stage absorption system. The total energy consumption for CO₂ capture is 1.22 GJ/tonne-CO₂ or less, where the total energy consumption for CO₂ capture is defined as (reboiler duty / steam boiler efficiency + pump electricity consumption x electricity-heat conversion factor / power generation efficiency) / CO₂ flow rate.
Figure 3. CO₂ capture process of the Tomakomai CCS demonstration project

The reduction of the reboiler duty is a key factor in reducing the running cost of the CO₂ capture facilities. As far as we know, the Tomakomai CCS facility is the first CCS plant applying a two-stage absorption system with low-pressure flash tower.

3.3. Reservoirs and the injection points

The Tomakomai project uses two reservoirs for CO₂ storage. The deep reservoir is the Takinoue Formation (T1 Member), located at a depth of approximately 2,400 m to 3,000 m below the seabed. This reservoir is a Miocene saline aquifer composed of volcanic and volcaniclastic rocks and is approximately 600 m thick. Before the drilling of the injection well, the Takinoue formation was estimated to have a porosity of 20 to 40% and a permeability of 9 to 25 md. The Takinoue formation is overlain by Miocene mudstones (Fureoi Formation, Biratori-Karumai Formation and Nina Formation) which act as cap rocks with a total thickness of approximately 1,000 m, as illustrated in Figure 4. The Takinoue formation is an anticlinal structure with a NNW-SSE trending axis and the planned storage interval is located in the north-eastern wing of the anticline about 4 km offshore.

Figure 4. Schematic geological cross section of the Tomakomai demonstration site
The shallow reservoir is a sandstone layer of the Moebetsu Formation, located at a depth of approximately 1,000 m to 1,200 m below the seabed. This reservoir is a Lower Quaternary saline aquifer and is approximately 100 m thick. Before the drilling of the injection well, the Moebetsu formation was estimated to have a porosity of 3 to 19% and a permeability of 0.01 md to 7 md. The reservoir is overlain by a thick mudstone layer of the Moebetsu Formation (approximately 200 m thick) which serves as a cap rock, as illustrated in Figure 4. The Moebetsu Formation has a gentle monocline structure with a NE dip of 1 to 3 degrees at the planned storage interval located 3 km offshore.

3.4 Injection wells

Drilling of the two injection wells started in October 2014 and was completed in July 2015. Two highly deviated injection wells were drilled from an onshore site and targeted the most prospective intervals of each reservoir determined from analyses of 3D seismic surveys conducted in 2009 and 2010.

The injection well for the Takinoue Formation, IW-1, has a maximum inclination of 72 degrees with a drilled depth of 5,800 m, vertical depth of 2,753 m and horizontal reach of 4,346 m (Figure 5). The injection interval of IW-1 completed with perforated liners achieves a length of 1,134 m. The brine injection test conducted shortly after the drilling and completion of IW-1 indicated that the injectivity of the Takinoue formation was very low (nano darcy order in permeability).

The injection well for the Moebetsu Formation, IW-2, is an extended reach drilling (ERD) well with a maximum inclination of 83 degrees, a drilled depth of 3,650 m, vertical depth of 1,188 m and horizontal reach of 3,025 m (Figure 6). The injection interval of IW-2 of 1,194 m in length is completed by perforated liners covered by sand control screens. The perforated liners and sand control screens help minimize sand flow back into the well. The brine injection test immediately following the drilling and completion of IW-2 indicated that the injectivity of the Moebetsu formation was very high (hundreds millidarcy order in permeability). The injection test results of the two reservoirs necessitated a revision of the initial injection plan (Section 4).

![Figure 5. Profile of the injection well (IW-1) for the Takinoue Formation](image-url)
In order to confirm that CO$_2$ is injected and stored safely and stably, it is necessary to monitor the behavior of CO$_2$ in the reservoirs and to set up systems to detect CO$_2$ movement out of the reservoirs. As Japan is highly susceptible to earthquakes, it is also necessary to allocate systems to measure and verify any correlation (or disrelation) between CO$_2$ storage and seismicity. The construction and deployment of the monitoring facilities were completed by January 2014 so that baseline observation could be started at least one year prior to the commencement of CO$_2$ injection. Table 1 shows the planned monitoring items and Figure 7 illustrates the layout of the monitoring facilities that have been established.

In the injection wells, CO$_2$ injection rates, bottom hole temperatures and pressures are continuously monitored along with wellhead temperatures and pressures of the injected CO$_2$. Temperature & pressure sensors and downhole seismometers have been installed in three observation wells. A permanent ocean bottom cable (OBC) 3.6 km long with 72 seismometers has been installed directly above the storage points of the reservoirs. Four ocean bottom seismometers (OBSs) have been placed above and surrounding the storage points. One onshore seismic station was constructed in the northwestern part of Tomakomai City. Using the seismometers in the observation wells, the OBC, the OBSs and the onshore seismic station, the monitoring of micro-seismicity and natural earthquakes started on February 1$^{st}$ 2015, thirteen months before the start-up of CO$_2$ injection.

A 3D seismic survey of the working area (3.8 km$^2$×4.1 km) was firstly conducted in 2009. Time lapse 3D seismic surveys are scheduled to be performed twice over the same area until the project ends in JFY 2020. 2D seismic surveys are also planned to be conducted using temporal deployment type OBCs along with the permanently installed OBC alignment in the years when 3D seismic surveys are not scheduled. In total, four 2D seismic surveys will be conducted (including the baseline survey conducted in 2013). Since the sensor locations of the permanently installed OBC are fixed, highly accurate data are expected to be obtained in the repeated 2D seismic surveys.
Table 1. Monitoring items

<table>
<thead>
<tr>
<th>Items</th>
<th>Observed objects</th>
<th>Observation frequency</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>Injection well</td>
<td>◆ Downhole: Temperature and pressure</td>
<td>Continuous</td>
<td>• Injection well for Takinoue Formation</td>
</tr>
<tr>
<td></td>
<td>◆ Wellhead: Pressure, Injection rate of CO₂</td>
<td></td>
<td>• Injection well for Moebetsu Formation</td>
</tr>
<tr>
<td>Observation well</td>
<td>◆ Downhole: Temperature and pressure, micro-seismicity and natural earthquakes</td>
<td>Continuous</td>
<td>• Observation well OB-1 for Takinoue Formation</td>
</tr>
<tr>
<td></td>
<td>◆ Signal of 2D seismic survey</td>
<td></td>
<td>• Observation well OB-2 for Moebetsu Formation</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>• Observation well OB-3 for Takinoue Formation</td>
</tr>
<tr>
<td>OBC : permanently installed Ocean Bottom</td>
<td>◆ Micro-seismicity and natural earthquakes</td>
<td>Continuous</td>
<td>• OBC line passes directly above the injection points of reservoirs.</td>
</tr>
<tr>
<td>Cable</td>
<td></td>
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</tr>
<tr>
<td>OBS : Ocean Bottom Seismometer</td>
<td>◆ Micro-seismicity and natural earthquakes</td>
<td>Continuous</td>
<td>• One wired OBS above the injection points</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>• Three stand-alone OBSs at the surrounding area of injection points of</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>reservoirs</td>
</tr>
<tr>
<td>Onshore seismometer</td>
<td>◆ Micro-seismicity and natural earthquakes</td>
<td>Continuous</td>
<td>• Northwestern region of Tamakomai city</td>
</tr>
<tr>
<td>2D seismic survey</td>
<td>◆ Distribution of CO₂</td>
<td>Periodic</td>
<td>• Utilizing OBC as seismic sensors</td>
</tr>
<tr>
<td>3D seismic survey</td>
<td>◆ Distribution of CO₂</td>
<td>Periodic</td>
<td>• A baseline survey was completed during the investigation period.</td>
</tr>
<tr>
<td>Marine environmental monitoring</td>
<td>◆ Chemical, physical and biological data</td>
<td>Periodic</td>
<td>• Monitoring plan is to be drawn up after the baseline survey and</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>marine environmental impact assessment.</td>
</tr>
</tbody>
</table>

Figure 7. Layout of the monitoring facilities
Between February 1st and April 5th 2015, 9 micro-seismic events ranging from Mw -0.09 to 0.24 in magnitude with hypocenter depths ranging from 5.9km to 8.6km were observed in the micro-seismicity monitoring area of 6km x 6km, and constituted the baseline of the micro-seismicity of the project site before initiating the CO2 injection (Figure 8).

4. CO2 injection

In the initial injection plan for the Tomakomai project, the maximum injection rates for both the Takinoue and Moebetsu formations were about 200,000 tonnes per year, corresponding to the maximum PSA offgas supply from the oil refinery. However, on account of the result of the brine injection test of the injection well IW-1, it became necessary to decrease the maximum injection rate of the Takinoue formation and install an additional CO2 flowmeter to accommodate the lower flow rate.

Consequently, the CO2 injection plan was revised as follows:
- Maximum injection rate for Takinoue formation: less than 1,000 tonnes per year
- Maximum injection rate for Moebetsu formation: about 200,000 tonnes per year
- Total implementation term of CO2 injection: April 2016 to March 2019
- Test injection into Moebetsu formation: April 6th to May 24th 2016
- Installation of additional flowmeter for Takinoue formation: October 2016
- Main injection into Moebetsu formation: November 2016 to March 2019
- Test injection into Takinoue formation: March 2017 to May 2017
- Main injection into Moebetsu and Takinoue formation: July 2017 to March 2019 (simultaneous injection into both reservoirs)
Figure 9. Result of the test injection into the Moebetsu formation

Test injection into the Moebetsu formation for reservoir evaluation was conducted between April 6th and May 24th, 2016, and a cumulative amount of 7,162.9 tonnes of CO$_2$ of was injected. The test was a step-rate injection test with several CO$_2$ injection rates as shown in Figure 9. The maximum injection rate was 210,000 tonnes per year. Before proceeding with the test injection, the maximum limit of bottom hole pressure was set as the operational limit of the CO$_2$ injection. The value of 12.6MPaG is 90% of the leakoff pressure of the cap rock obtained from the XLOT (extended leakoff test) conducted shortly after completion of the injection well IW-2. The initial bottom hole pressure of the injection well IW-2 was 9.3MPaG and the maximum bottom hole pressure recorded during the test injection was 10.0MPaG, much lower than the operational limit pressure, meaning that the injectivity of the Moebetsu formation is very high.

Since May 24th 2016, the injection well for Moebetsu formation has been in the fall-off test stage and the reservoir character analyses of the Moebetsu formation are being continued. Since the commencement CO$_2$ injection in April 6th 2016, no micro-seismic events have been detected in the micro-seismicity monitoring area, as shown in Figure 8.

5. Social Outreach Activities

As the CCS demonstration project is being conducted in the offshore area of the Tomakomai Port, the understanding and support of the local government, industry, and community are a must. The City of Tomakomai has a legacy of a high awareness of environmental issues, having proclaimed itself as a "Human Environmental City" as early as in 1973. When the city learned in 2009 that a geological survey was being conducted in offshore Tomakomai regarding its feasibility as a candidate site for CO$_2$ storage, it saw early on that a CCS demonstration project at Tomakomai could become a basic model for CCS in Japan. Garnering the support of major local companies, industrial associations and fishing unions, the city established the "Tomakomai CCS Promotion Association" in April 2010, in order to bring the demonstration project to Tomakomai, and to communicate information on CCS to its residents. The local fishing cooperatives have also been very supportive of the
demonstration project, and JCCS has maintained very close communications and consultations with the cooperatives ever since the preparatory stages of the project to ensure that the CCS project and fishing activities can coexist.

In answer to the requests for (i) disclosure of information, (ii) consideration for safety and communication of associated risks, (iii) dissemination of information to the young generation, expressed by Tomakomai residents in a survey, JCCS has conducted extensive social outreach activities in Tomakomai and other areas since JFY 2011. A wide range of activities; panel exhibitions, forums for the residents, science classes for schoolchildren, seminars for senior citizens, site visits, etc., is being carried out. In addition, in order to enhance the awareness and understanding of CCS by the general public, JCCS conducts seminars on CCS at Japanese universities and industrial associations and participates in large exhibitions on environmental and global warming issues in Japan and abroad.

Regarding the number of visitors (domestic and international) to the Tomakomai site, 1,600 people visited the site in JFY 2015, a three-fold increase from the year before, reflecting the growing interest in the Tomakomai CCS demonstration project.

6. Conclusion

The Tomakomai CCS demonstration project, planned for the period JFY 2012 to 2020 aims to demonstrate and verify the technical viability of a full cycle CCS system from capture through injection and storage. Unique features of the project include an energy efficient CO2 capture facility, and onshore to offshore injection into two separate reservoirs by two dedicated deviated injection wells.

The demonstration facilities comprising the CO2 capture facility, CO2 injection facility, two injection wells, three observation wells and various onshore and offshore monitoring systems were completed during the first four-year period (JFY 2012 – 2015). The project will capture and store 100,000 tonnes per year or more of CO2 from JFY 2016 to 2018. The CO2 injection into the shallow Moebetsu Formation started in April 2016, and the test injection results indicate that the injectivity of this reservoir is very high.

The project is being carried out in the port area of Tomakomai City, and a wide range of public outreach programs have been developed and are being run in parallel with the implementation of the project.

Acknowledgment

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References