TOSHIBA

CASE STUDY

CO_2 Capture Project Integrated with Mikawa Biomass Power Plant

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Abstract

Toshiba Energy Systems & Solutions Corporation has constructed and started the operation of a CO_2 Capture Demonstration Plant in 2020. This was carried out as part of the "Sustainable CCS Project" commissioned by Ministry of the Environment, Government of Japan.

This Demonstration Plant treats the flue gas from the Mikawa Power Plant fueled with 100% biomass. This plant can be a part of total BECCS system, once captured CO_2 is transported and stored deep under the sea bed located in the offshore of Japan. This Demonstration Plant captures more than 600 tons-CO_2/day which corresponds to more than 50% of emitted CO_2 from the Mikawa Power Plant. Both plants are fully integrated with flue gas and steam cycle systems.

In this project, mitigation method for amine emission from CO_2 capture plant was developed. This new technology was installed in the Demonstration Plant and the performance was evaluated.

Keywords: CO_2 capture; Demonstration Plant; BECCS; integrated; amine emission

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1. Introduction

In 2020, Toshiba Energy Systems & Solutions Corporation (Toshiba ESS) has constructed and started the operation of a CO_2 Capture Demonstration Plant at an area near the Mikawa Power Plant (capacity: 50MW) operated by Toshiba ESS's subsidiary, SIGMA POWER Ariake Corporation, in Omuta, Fukuoka prefecture, Japan (Figure 1). This was carried out as part of the "Sustainable CCS Project" commissioned by Ministry of the Environment, Government of Japan (MOEJ).

Figure 1. CO_2 Capture Demonstration Plant

This Demonstration Plant has three features listed below:

1. The Mikawa Power Plant is fueled with palm kernel shells (PKS) as the fuel source for biomass energy generation. Therefore, this Demonstration Plant can be a part of total BECCS system, once this captured CO_2 is transported and stored deep under the sea bed located in the offshore of Japan, which is a future plan.
2. This Demonstration Plant captures more than 600 tons-CO_2/day from the Mikawa Power Plant and this corresponds to more than 50% of its total emissions. This Demonstration Plant is fully integrated with the Power Plant, with turbine extraction steam feeding the energy for desorbing CO_2 at the stripper.
3. In this project, mitigation method for amine emission from absorber was developed. This developed novel technology was installed in the washing tower of the Demonstration Plant and the performance was evaluated.

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This Sustainable CCS Project was carried out by 18 entities from FY2016 to 2020, including Toshiba ESS as a representative organization. Toshiba ESS was responsible for constructing and operating this Demonstration Plant.

Toshiba ESS has been developing post-combustion amine-solvent CO_2 capture technology since 2007, and already operates a Pilot Plant that can capture 10 tons of CO_2 a day from 2009 at the Mikawa Power Plant [1][2]. This has been used to verify and demonstrate practical operation of the system, including its performance, operability and maintainability. These developed technology and know-how has been fully applied to the design of the Demonstration Plant. Toshiba solvent-1 (TS-1) is used as a solvent in this plant.

The layout of the Mikawa Power Plant and these two CO_2 capture plants are shown in Figure 2. This Power Plant was modified and changed its fuel from coal to PKS in 2017. Both CO_2 capture plants treat the flue gas from this Power Plant.

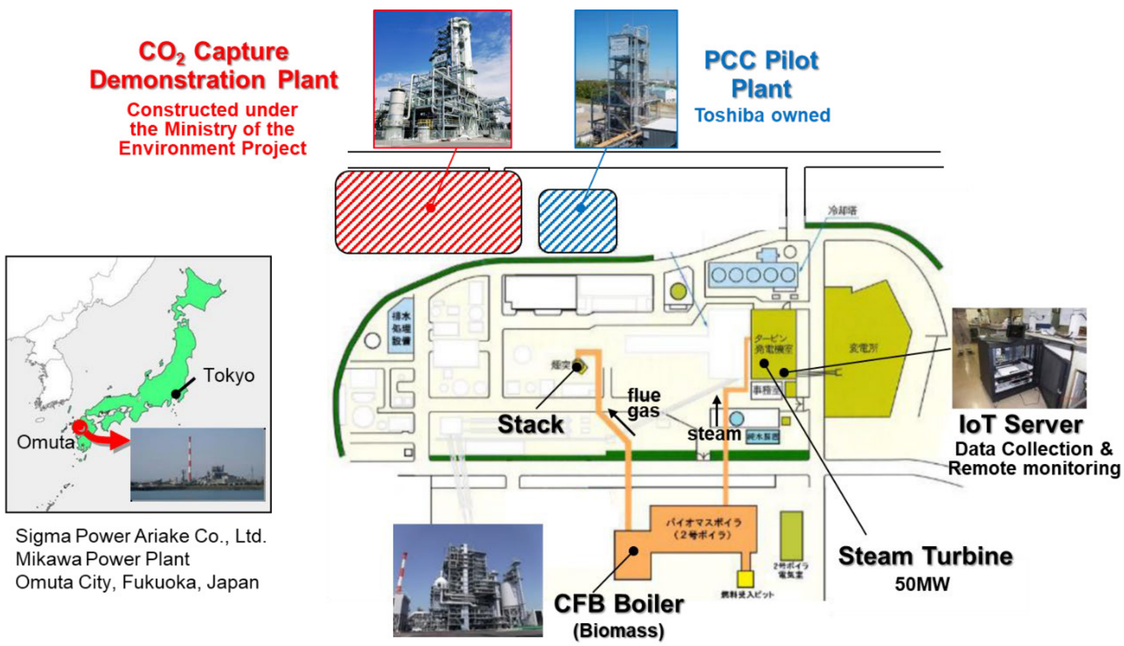

Figure 2. Layout of the Mikawa Power Plant and CO_2 capture plants

2. CO_2 Capture Performance

2.1 ABOUT THE DEMONSTRATION PLANT

Figure 3 shows the schematic view of the Mikawa Power Plant with the Demonstration Plant which is inside the dotted line. These two plants are fully integrated in the aspect of both steam cycle system and flue gas system. Steam for the reboiler is extracted from the steam turbine generator and condensate is returned to the deaerator. The amount of extracted steam is around 1/6 of the steam cycle in the rated operation of these plants. About 60% of the flue gas emitted from the Mikawa Power Plant is introduced into the absorber after cooled down by the GGH (Gas-Gas-Heater) and treated flue gas is heated before returning to the flue gas duct of the Power Plant. Average CO_2 concentration in the flue gas is 15 vol.% in dry base.

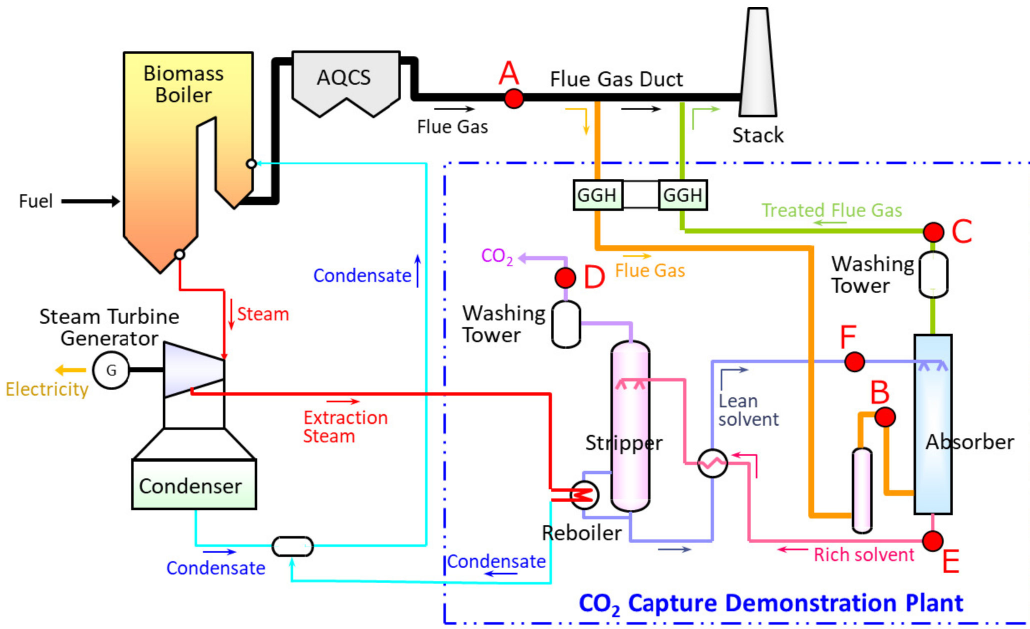

Figure 3. CO_2 Capture Demonstration Plant with BECCS capability

2.2 CONTINUOUS RUNNING TEST

48 hrs continuous running test results is shown in Figure 4. The amount of captured CO_2 was calculated from measured data at point D in Figure 3. From the flue gas of the Mikawa Power Plant, CO_2 was stably captured at the average rate of 640 tons per day. In this 48 hrs operation, CO_2 capture efficiency defined in Equation 1 was 95% on average. Amount of CO_2 in the flue gas at the inlet of the absorber was calculated from measured data at point B.

In this operation period, CO_2 capture ratio defined in Equation 2 was 54% on average, which means more than half of CO_2 emitted from the biomass boiler was captured. Amount of CO_2 in the flue gas of the Mikawa Power Plant was calculated from measured data at point A, which was 1200 tons per day.

Through this continuous running test, stable operation in terms of capturing CO_2 at capture plant as well as generating electricity at power plant was accomplished.

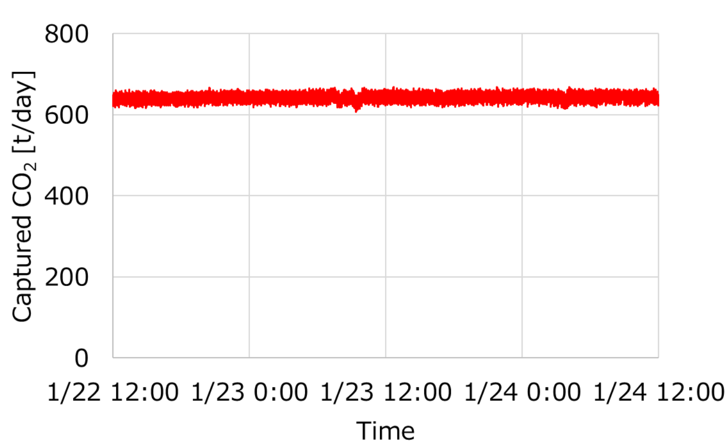

Figure 4. Trend data of captured CO_2 in continuous running test

$$ECO2 = \frac{\dot{m}CO2_{str}}{\dot{m}CO2_{abs\_in}} \times 100 \qquad RCO2 = \frac{\dot{m}CO2_{str}}{\dot{m}CO2_{mpp}} \times 100$$

Where,

$ECO2 : CO_2\ capture\ efficiency\ [\%]$

$RCO2 : CO_2\ capture\ ratio\ [\%]$

$\dot{m}CO2_{str} : CO_2\ flowrate\ in\ the\ gas\ at\ the\ outlet\ of\ the\ stripper\ [t/day]\ \cdots point\ D$
$(= Captured\ CO_2\ calculated\ on\ the\ stripper\ side\ [t/day])$

$\dot{m}CO2_{abs\_in} : CO_2\ flowrate\ in\ the\ flue\ gas\ at\ the\ inlet\ of\ the\ absorber\ [t/day]\ \cdots point\ B$

$\dot{m}CO2_{mpp} : CO_2\ flowrate\ in\ the\ flue\ gas\ of\ the\ Mikawa\ Power\ Plant\ [t/day]\ \cdots point\ A$

2.3. VALIDITY OF CALCULATED AMOUNT OF CAPTURED CO_2

For enabling large scale CCUS deployment in the future, an adequate method to measure captured CO_2 is needed. One way to ensure this adequacy is to the mass balance of CO_2. For this purpose, we have calculated the amount of captured CO_2 during stable operation in three ways, namely, gas-absorber side, gas-stripper side, and solvent side. This checking is also recommended in ISO/TR 27912 published in 2016 [3].

Captured CO_2 on gas-absorber side is calculated with Equation 3. Captured CO_2 on gas-stripper side is CO_2 flowrate in the gas at the outlet of the stripper, which was mentioned in the previous section. Captured CO_2 on the solvent side is calculated with Equation 4, in which CO_2 flowrate in the solvent is calculated with multiplying solvent flowrate and CO_2 loading in the solvent.

Table 1 is the average results in three measurement times during above-mentioned 48 hours continuous running test. In the middle of each measurement time, rich and lean solvents were sampled and CO_2 loadings were analyzed. Using calculated captured CO_2 amounts in three ways, Toshiba checked the ratio of the difference between maximum and minimum value to the average value. The results were 1.6%, 3.0%, and 2.5%, respectively at each measurement time.

$$\dot{m}CO2_{abs} = \dot{m}CO2_{abs\_in} - \dot{m}CO2_{abs\_out}$$

$$\dot{m}CO2_{sol} = \dot{m}CO2_{rich} - \dot{m}CO2_{lean}$$

Where,

$\dot{m}CO2_{abs} : Captured\ CO_2\ calculated\ on\ the\ absorber\ side\ [t/day]$

$\dot{m}CO2_{abs\_out} : CO_2\ flowrate\ in\ the\ flue\ gas\ at\ the\ outlet\ of\ the\ absorber\ [t/day]\ \cdots point\ C$

$\dot{m}CO2_{sol} : Captured\ CO_2\ calculated\ on\ the\ solvent\ side\ [t/day]$

$\dot{m}CO2_{rich} : CO_2\ flowrate\ in\ the\ rich\ solvent\ [t/day]\ \cdots point\ E$

$\dot{m}CO2_{lean} : CO_2\ flowrate\ in\ the\ lean\ solvent\ [t/day]\ \cdots point\ F$

Data acquisition time	Solvent sampling time	Calculated captured CO_2 [t/day]		
		Gas side		Solvent side $\dot{m}CO2_{sol}$
		Absorber side $\dot{m}CO2_{abs}$	Stripper side $\dot{m}CO2_{str}$	
1/22 10:00～12:00	1/22 11:00	630.5	640.6	637.8
1/23 10:00～12:00	1/23 11:00	629.2	643.3	648.2
1/24 10:00～12:00	1/24 11:00	638.2	642.6	626.7

Table 1. Captured CO_2 in continuous running test calculated in three ways

2.4. VARIABLE OPERATION TEST

In general, thermal power plants are likely to become adjustable power sources for renewable energy. Therefore, CO_2 capture plants applied to thermal power plants must have the ability to follow the load changes of thermal power plants adequately. In this test, to simulate responding to the load changes of thermal power plants, the inlet gas flow rate to the absorber and steam flow rate to the stripper was simultaneously changed from rated condition (100%) to 50% during 30 minutes, and after holding about 1 hour, raised up to 100% again. Figure 5 shows the result. The amount of captured CO2 was calculated from measured data at point D in Figure 3. During this test period, no problem was detected in the operation of both the Demonstration Plant and the Mikawa Power Plant.

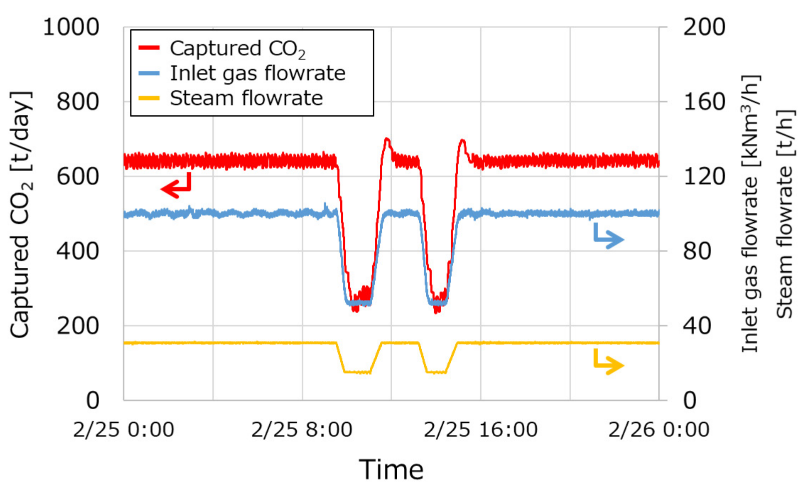

Figure 5. Trend data in variable operation test

3. Mitigation of Amine Emission Performance

3.1 BACKGROUND

As a part of Sustainable CCS Project, Toshiba ESS has investigated amine emissions using above mentioned Pilot Plant [4][5][6]. In this Pilot Plant, conventional washing system with packed bed for the absorber outlet gas is applied.

Figure 6 shows result of the TS-1 test. The left graph shows total amine emissions in black bar and amine emissions of mist phase with various mist size in colored bar at the outlet of absorber. In the experiment, over 10 kinds of degraded amines including solvent component were detected, and identification numbers (e.g. T2) are given for each. Since amine emissions take the form of either mist or vapor, this graph allows Toshiba to confirm the ratio of mist based amine emissions against total amine emissions. As for species T2, mist based amine emissions occupied over 50% of total emissions and for T6, almost all emissions took the form of mist. We assume that the ratio of mist based amine emissions depends on amine properties such as amine vapor pressure.

The right graph shows relationship of number concentration of aerosol at the absorber inlet and that of amine mist at the absorber outlet or washing system outlet. The number of aerosol at the absorber inlet matched the number of amine mist at the absorber outlet, i.e. washing system inlet. This result implies that the aerosol acts as a source of amine mist nuclei and enhances amine mist growth in the absorber. This graph also shows that it is difficult to capture the mist derived from TS-1 using a conventional washing system with packed bed.

Based on this knowledge, we have developed a spray type mitigation method for amine emission with demister using a bench scale test plant [7]. This novel technology was installed in the washing tower of the Demonstration Plant and the performance was evaluated.

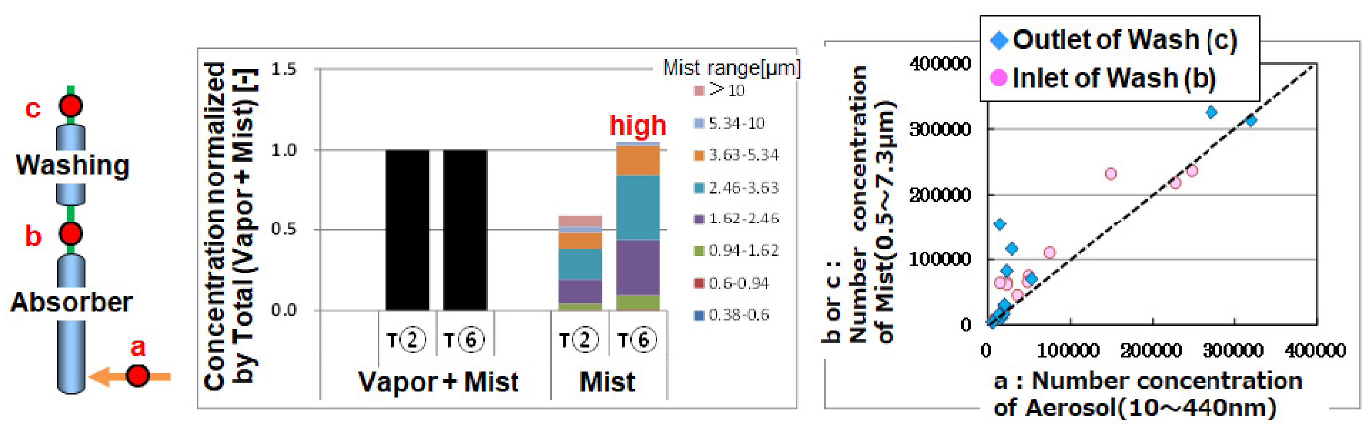

Figure 6. Trend data in variable operation test

3.2. MITIGATION METHOD INSTALLED IN THE DEMONSTRATION PLANT

Figure 7 shows three towers in the Demonstration Plant when these were under construction, and the spray type washing system was installed in the washing tower.

While operating this plant, we have investigated amine emissions using batch analysis with paying attention to three principles at gas sampling, i.e. isokinetic gas sampling, heating of sampling line, and keeping required length of straight gas duct. According to Figure 8, high washing efficiency using this system has become clear. In this graph, concentrations of total amine components are normalized with that at the absorber outlet (i.e. washing system inlet) of the Pilot Plant test. When conventional washing system with packed bed was applied, washing efficiency was around 40%. However, efficiency reached an impressive 95% when the novel spray system was adopted.

Figure 7. Towers in the Demonstration Plant

Figure 9 shows the result of mitigating amine mist emissions. This data was acquired with ELPI+ (Electrostatic Low Pressure Impactor). This result shows a drastic effect of suppressing amine mist effluent to the atmosphere.

In the washing tower of the Demonstration Plant, several types of washing systems has been installed, and we are continuing to conduct various tests.

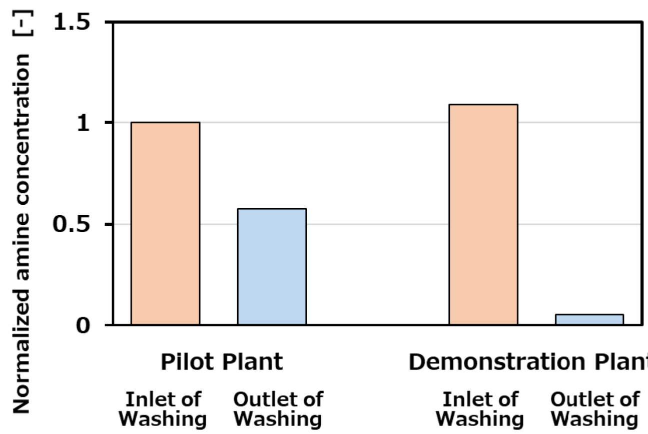

Figure 8. Comparison of amine concentrations in the Pilot Plant and the Demonstration Plant

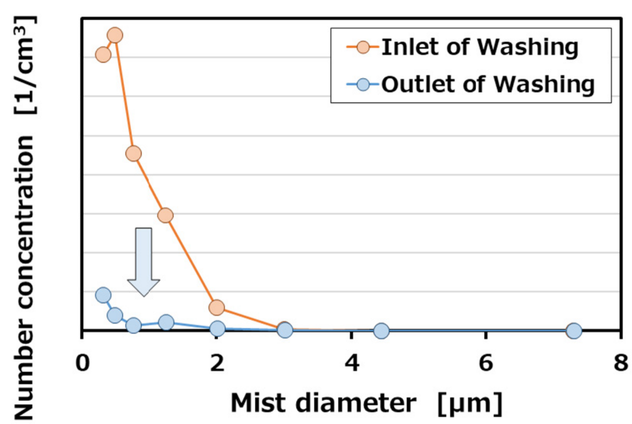

Figure 9. Reduction of amine mist emissions in the Demonstration Plant

4. Future Plan

In Figure 10, a future plan for the Sustainable CCS Project is illustrated. In Japan, the potential storage site of CO_2 is mainly located offshore and adopting CO_2 transport by ship to solve the problem of "source–sink unmatching" is reasonable. The 5-year project has started in FY2021, in which construction of the CO_2 liquefaction plant, design of the CO_2 loading facility and the CO_2 transport/injection ship, investigation and decision of offshore storage site are planned. MOEJ has an impressive design in which total verification from capture to storage including monitoring will be accomplished by 2030 in Japan.

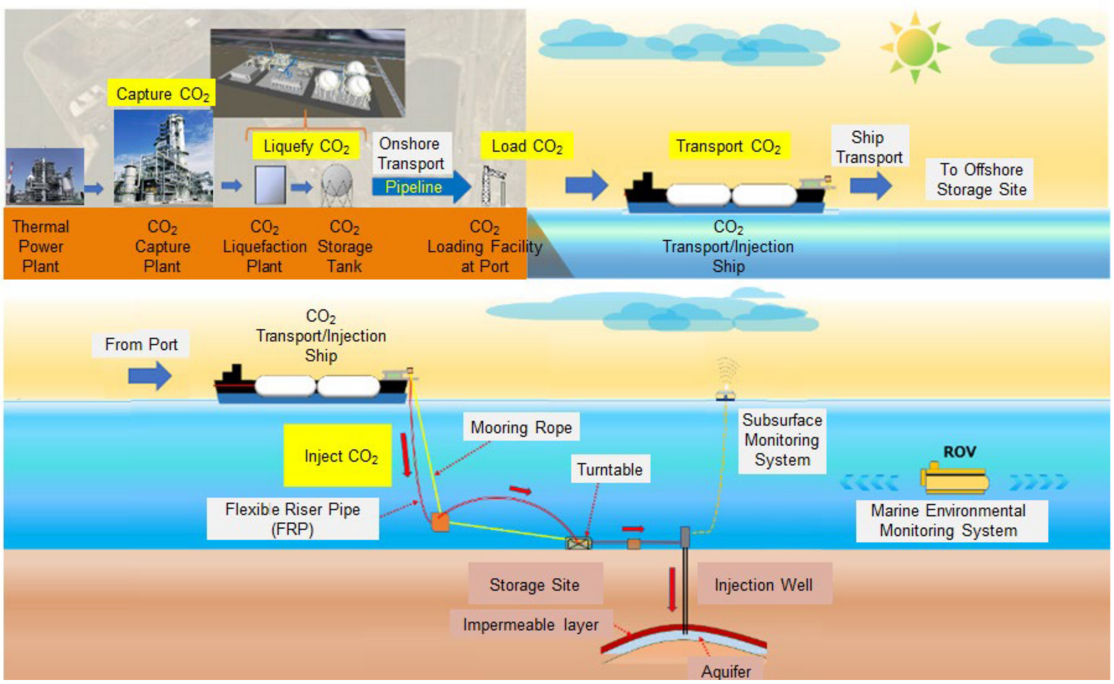

Figure 10. Future plan

5. Summary

As part of the Sustainable CCS Project, Toshiba Energy Systems & Solutions Corporation has constructed and started the operation of a CO_2 Capture Demonstration Plant with BECCS capability.

Fully integrated with the Mikawa Power Plant, this Demonstration Plant accomplished stable operation at the average capture rate of 640 tons per day, which corresponds to more than 50% of the CO_2 that is emitted from the Mikawa Power Plant. This Demonstration Plant also showed the possibility to follow the load changes of thermal power plants without any problem.

In this project, a spray type mitigation method for amine emission from CO_2 capture plant was developed. This new technology was installed in the Demonstration Plant and the outstanding performance compared to conventional packed bed type washing system was verified.

Starting with this CO_2 Capture Demonstration Plant, a series of facilities and the transport of CO_2 offsite from capture to storage is on the horizon by 2030, according to the Ministry of Environment Japan's (MOEJ) plans for Japan.

Acknowledgements

Commission for this “Sustainable CCS Project” by Ministry of the Environment, Government of Japan is gratefully acknowledged.

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