LCA study on the international cooperation of carbon circulation by Cryo-DAC and CN-methane

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Overview

Efforts to capture and store CO_2, which is the primary cause of global warming, are accelerating toward the realization of net-zero emissions, and various capture technologies are being developed. The chemical absorption method using an amine absorbent for CO_2 capture is suitable for capturing large amounts of atmospheric CO_2 (i.e., direct air capture) because of its excellent scalability. However, a limitation is that the absorption liquid needs to be heated with a large amount of external heat to release the absorbed CO_2 and regenerate the absorption liquid.

To solve this, we are developing a novel energy-conserving direct air capture technology, Cryo-DAC, which directly captures CO_2 using the unused cold heat of liquefied natural gas (LNG). Cryo-DAC technology uses the unused cold heat of LNG to sublimate CO_2 into dry ice, causing decompression in the sublimation vessel connected to the absorption tower. Consequently, the absorption tower is depressurized and CO_2 is released; thus, requiring no external energy input.

In this study, we consider an international cooperation of carbon circulation in which CO_2 emitted by the combustion of imported LNG in Japan is directly captured from the atmosphere by the Cryo-DAC system and that emitted from the combustion exhausts at LNG thermal power plants is captured by other technologies. The captured CO_2, which is rich in renewable energy, is exported overseas, and carbon-neutral methane (CNM) is synthesized with green hydrogen produced from renewable energy and exported to Japan as liquefied CNM (LCNM). We examined such a carbon circulation model from the perspectives of economic evaluation and life cycle assessment (LCA) analysis.

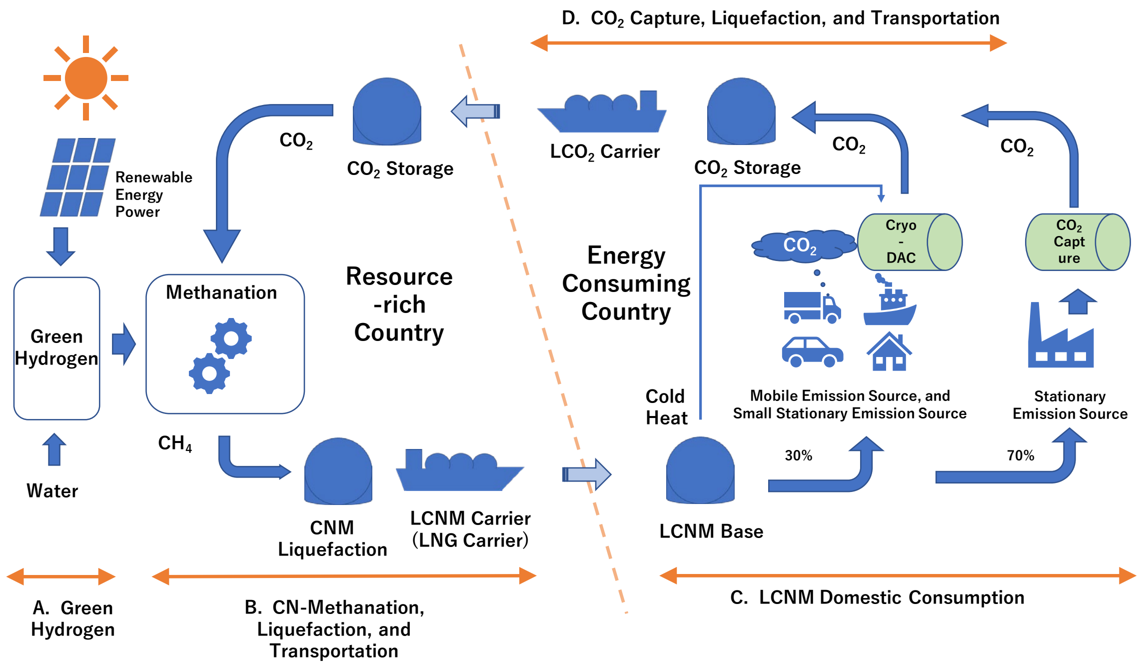
Methods

Using methane, which is a typical product synthesized from CO_2, as a case study on LCA evaluation methods for carbon capture and utilization (CCU) technology, NEDO (2021.3) calculated the life-cycle of CO_2 emissions of the carbon cycle system for the evaluation range of (1) hydrogen production, (2) CO_2 capture and storage from power generation and/or iron smelting processes, (3) procurement of other input raw materials, and (4) product manufacturing and transportation. Compared to the existing process, CCU technology has been reported to reduce CO_2 emissions by 74.1% to 82.2%. However, their evaluation target was limited to the life cycle of CO_2 emissions and the evaluation of economic efficiency was not included.

In our study, we consider an international cooperation of carbon circulation (see Figure 1), in which CO_2 is captured from the air by Cryo-DAC and the CO_2 direct capture technology of LNG thermal power plants in Japan, followed by international transport of the captured CO_2 to resource-rich countries. In contrast, using green hydrogen, produced in a resource-rich country, where reproducible energy can be used at low cost, CNM can be produced. The CNM is liquefied and shipped to Japan using an existing LNG supply chain. Assuming such sustainable carbon circulation, we will conduct an economic and environmental LCA analysis on economic efficiency and CO_2 emissions, verify the sustainability of the system, and examine potential challenges.

Therefore, assuming a domestic consumption of 1 ton of LCNM, we calculated the amounts of domestic CO_2 capture, green hydrogen production, internationally transported LCNM and CO_2, and energy input to each production process necessary for a stable carbon cycle. Next, we extracted the unit cost, unit energy input amount, and unit CO_2 emission amount at each step from the existing literature and obtained the cost evaluation of the entire system and the amounts of balance CO_2 emission and recovery using these coefficients.

CO_2 used as a resource as required in this carbon cycle system was obtained by Cryo-DAC, which uses LNG cold heat and CO_2 direct capture technology at LNG thermal power plants; however, the amount of CO_2 captured is slightly insufficient by itself, against the stable carbon circulation. Therefore, LNG is not substituted completely in this case (Case1), then we considered two variations (Case 2: CO_2 capture from thermal power generation other than LNG, Case 3: use of Cryo-DAC using cold heat resources other than LNG) to compensate for this shortage. In addition, we estimated the cases where the costs of water electrolysis and Cryo-DAC are reduced and the case where all options were implemented in Japan, and compared their results with the case of international cooperation.



Source: Drawn by the authors.

Table 1 International cooperation of carbon circulation by DAC-captured CO_2 and carbon-neutral (CN) methane

Results

Although following a sustainable carbon cycle system that captures and reuses CO_2 emitted by LCNM combustion, CO_2 emissions, in cases of fully replaced LNG by LCNM, were approximately 30% higher than CO_2 capture because there are CO_2 emissions owing to energy input in each process. Net CO_2 emissions in these cases are approximately 32% of the emission when only LNG is used.

Considering the carbon cycle system, the LCNM import price has been estimated to be approximately 377–434 thousand yen under the conditions of available researches. The total power input per ton of domestic LCNM consumption is approximately 25–29 MWh, 93% of which is used for green hydrogen production in the resource-rich country.

The cost share of LCNM is dominant in the green hydrogen production of 73-76%, followed by the CO_2 capture cost of 15-16%. If the cost of water electrolysis equipment in the green hydrogen production is sufficiently reduced to the level that hydrogen production cost become approximately 10 yen/m^3, the LCNM price is reduced to 165 thousand yen. Furthermore, if cost of Cryo-DAC is reduced additionally, the price would be 144 thousand. Though the price is higher than current LNG import price of 60 thousand yen per ton, this might be acceptable if policy support is available.

On the other hand, if all processes of the carbon cycle system are operated in Japan, the LCNM price will rise from 144 thousand yen to 355 thousand yen because the electricity price in Japan is relatively high. Of course, half-reduction of electricity price would reduce the LCNM price to 219 thousand yen.

Conclusions

We obtained the following tentative conclusions.

Operating everything domestically is expensive, and international cooperation with resource-rich countries will reduce costs. The model also matches the policy objectives of resource-rich countries aiming for industrialization. If the cost of water electrolysis and Cryo-DAC are sufficiently reduced, LNG might be replaced with CNM with policy support.

The carbon cycle system using CNM does not capture all the emitted CO_2 on the premise of sustainable CNM circulation, and the amount of CO_2 emitted is reduced to approximately 32% of that emitted when only LNG is used.

If other cold heat sources such as liquified hydrogen are used, the amount of CO_2 captured by the Cryo-DAC increases. There is a possibility that the net amount of CO_2 emissions will reach zero, although the cost increases slightly.

References

New Energy and Industrial Technology Development Organization (2021.3) “Survey on evaluation method of CO_2 reduction amount in the life cycle of products made from CO_2” (in Japanese).