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The Prospects of Clean and Green Hydrogen in Japan

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1 Introduction

Because of Japan's limited opportunities for geological CO_2 storage and its high population density which limits the availability of indigenous renewable energy, transition towards a "low-carbon society" in Japan poses special challenges. Here we explore the challenges and opportunities for the production and use of clean and green hydrogen for the Japanese transport sector. In this study, clean hydrogen is produced through natural gas reforming with CO_2 capture and storage (CCS), and green hydrogen is produced by wind power and water electrolysis at suitable locations, e.g. Patagonia. As transoceanic hydrogen transport systems, liquid hydrogen (LH_2) shipment and liquid organic hydrogen carrier (LOHC) shipment are considered. Imported LH_2 and LOHC are distributed to hydrogen station and produce hydrogen at the station.

Four energy systems are compared in this study. Case 1 is clean hydrogen transported by LH_2, Case 2 is clean hydrogen transported by LOHC, Case 3 is green hydrogen transported by LH_2 and Case 4 is green hydrogen transported by LOHC. We estimated the cost and CO_2 emission intensity of each case. The hydrogen supply cost in Case 2 (clean hydrogen with LOHC) is estimated as 6.5 \$/kg and is positioned as the most economically reasonable energy system, while the CO_2 emission is 5.7 kg-CO_2/kg-H_2. The CO_2 emission intensity in Case 3 (green hydrogen with LH_2) is as low as 0.7 kg-CO_2/kg-H_2 and is positioned as the least CO_2 emission energy system, while the cost of hydrogen is estimated as 10.5 \$/kg.

Starting from usage of domestically produced hydrogen, then importing clean hydrogen, and finally importing green hydrogen will be a realistic approach for realization of the hydrogen society in Japan,

2 Premises and Assumptions

It has been attempted to give this feasibility study as much as possible a real-world setting. The starting point for this was to envision implementation of hydrogen production and retail in the Tokyo metropolitan area in the 2015-2020 timeframe, in accordance with the assumptions of METI for hydrogen vehicle rollout. A total fleet of 900,000 hydrogen vehicles is foreseen at that time, consuming a grand total of 150 ton per day (tpd) hydrogen. We assumed a 50 tpd "central liquid" production by natural gas steam reforming without CCS. This case is called "domestic production". The cost of this hydrogen production and delivery pathway was estimated as 5.6 \$/kg and CO_2 emission intensity was estimated as 11.6 kg/kg [1], [2], [3]. These numbers are as a reference against which the cost of further CO_2 reductions of Cases 1 through 4 are measured.

Figure 1 shows a hydrogen energy chain including the four energy systems (clean hydrogen with LH_2, clean hydrogen with LOHC, green hydrogen with LH_2 and green hydrogen with LOHC). For the study of hydrogen production through natural gas reforming with CCS, LH_2

distribution and supply at a forecourt station is evaluated. For the study of hydrogen production by wind power, we assumed 45% operating rate and 900 $/kw each for wind turbine, transmission construction and electrolyzer. For the study of hydrogen importing, we assumed LH_2 case and LOHC case. The LH_2 case was evaluated based on WE-net project, which was done by NEDO in Japan. For the LOHC case, we assumed a Very Large Crude oil Carrier (VLCC) oil tanker to carry decalin and naphthalene as the hydrogen carrier. The assumed distance is 5,000 km.

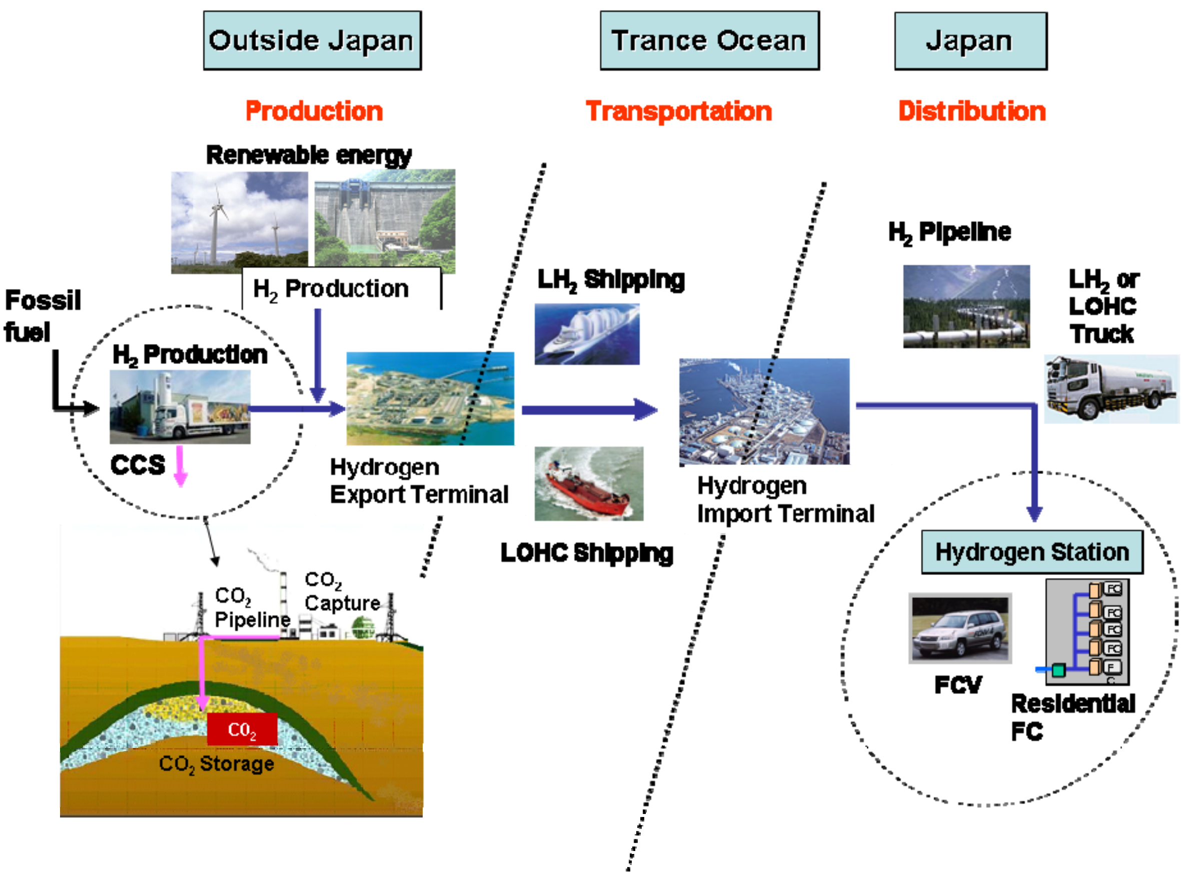

Figure 1: Hydrogen energy chain including the four energy systems (Case 1: clean hydrogen transported by LH_2, Case 2: clean hydrogen transported by LOHC, Case 3: green hydrogen transported by LH_2 and Case 4: green hydrogen transported by LOHC.)

3 Results and Discussion

Table 1 shows the results from our estimation. The cost of clean hydrogen with LOHC (Case 2) is estimated as 6.5 $/kg and is positioned as the most economically reasonable energy system, while the CO_2 emission is 5.7 kg-CO_2/kg-H_2 [4] The CO_2 emission intensity of green hydrogen with LH_2 (Case 3) is estimated as low as 0.7 kg-CO_2/kg-H_2 and is positioned as the least CO_2 emission energy system, while the cost of hydrogen is estimated as 10.5 $/kg.

Table 1: Hydrogen cost, CO_2 Emission Intensity and CO_2 Avoided cost of each case.

	Hydrogen Cost	CO_2 Emmision Intencsity	CO_2 Avoided Cost
1. NG+CCS LH_2	8.0 $/kg	5.1 kg/kg	152 $/t-CO2
2. NG+CCS LOHC	6.5 $/kg	5.7 kg/kg	154 $/t-CO2
3. Renewable LH_2	10.5 $/kg	0.7 kg/kg	450 $/t-CO2
4. Renewable LOHC	8.9 $/kg	4.5 kg/kg	453 $/t-CO2

CO_2 reduction cost analysis is one of the important methods to assess the CO_2 reduction potential and the public financial burden. RITE (Research Institute of Innovative technologies for the Earth) presented their analysis, and the image of their estimation is shown in Figure 2 [5]. The CO_2 reduction cost for the previous government's midterm target in Japan (-15% CO_2 reduction by 2020 comparing with 2005) is calculated as $151/t-$CO_2$. The CO_2 reduction cost for the present government's midterm target in Japan (-25% CO_2 reduction by 2020 comparing with 1990) is calculated as $476/t-$CO_2$. Nuclear power facilities and CCS technologies are not included in this analysis because of uncertainty in availability of these technologies in that time frame. The CO_2 avoidance cost of clean hydrogen with LOHC (Case 2) is 154 $/t-$CO_2$, which is similar to the CO_2 abatement cost of the previous government's target in Japan. The CO_2 avoidance cost of green hydrogen with LH_2 (Case 3) is 450 $/t-$CO_2$, which is a littlie bit lower than the CO_2 abatement cost of the present government's target in Japan.

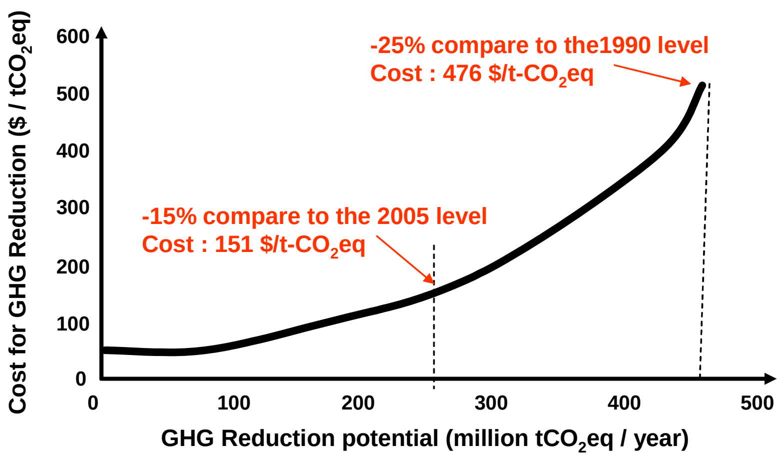

Figure 2: CO_2 reduction cost curve of Japan (by RITE) [6].

Figure 3 shows the breakdown of hydrogen cost estimated here. Comparing the hydrogen cost transported by LOHC (Case 2 and 4), cost for production has big difference. It means, we should try to decrease the cost of hydrogen production by wind power to reduce the cost of green hydrogen. The cost of hydrogen production by wind power consists of fixed cost for wind turbine, construction of transmission and electrolyzer. The variable costs are not significant because all required energy can be supplied by electricity produced by free wind. Large-scale wind power is rapidly spreading these days, and the cost of wind turbine and construction of transmission will significantly go down in future. R&D for economical large-scale electrolyzer will be needed for further reduction of hydrogen production cost by wind power.

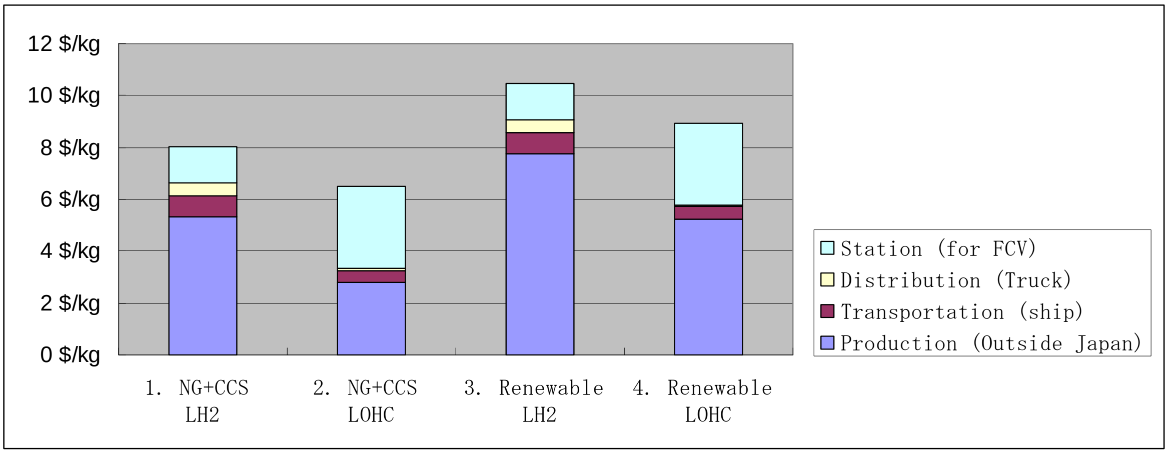

Figure 3: Breakdown of hydrogen cost.

Figure 4 shows the breakdown of CO_2 emission intensity estimated here. Over 90% of CO_2 is emitted at the station in both green hydrogen cases (Case 3 and 4). When LH_2 is used for hydrogen carrier, all CO_2 emission at the station is attributed to electricity consumption. When LOHC is used for hydrogen carrier, most CO_2 emission at the station is attributed to natural gas consumption for de-hydration. Case 3 needs most of energy at production and is supplied by CO_2 free electricity. Case 4 needs most of energy at station and required heat for heating the de-hydration reactor is supplied by natural gas burning without CCS. If the CO_2 emission intensity of heat source for case 4 becomes lower, the CO_2 emission intensity of case 4 becomes lower. Waste heat from CHP or solar heating can be considered for such heat sources.

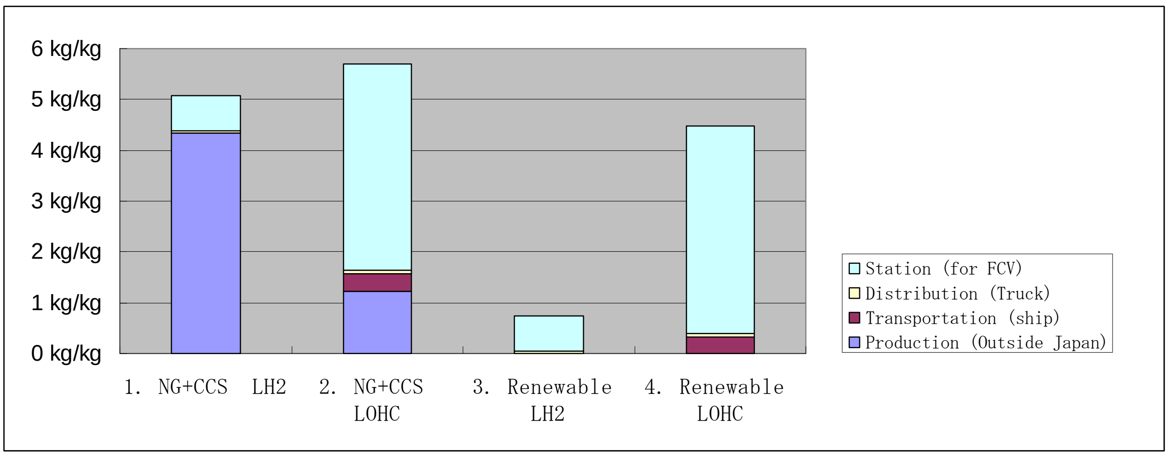

Figure 4: Breakdown of CO_2 emission intensity.

Figure 5 shows Well to Wheel CO_2 emission intensity of H_2-FCV comparison with gasoline vehicles. CO_2 emission intensity of gasoline vehicle and FCV's efficiency is assumed based on the study by JHFC [6]. Well to wheel CO_2 emission intensity of FCV depends on hydrogen source. When FCV is fueled by domestically produced hydrogen without CCS, the CO_2 intensity becomes around 1/2 comparing with that of gasoline ICE. When FCV is fueled domestically produced clean hydrogen or is fueled by imported clean hydrogen transported by LOHC, the CO_2 emission intensity becomes around 1/4 comparing with that of gasoline ICE. When FCV is fueled by imported green hydrogen transported by LH_2, CO_2 emission intensity becomes less than 1/30 comparing with that of gasoline ICE.

Importing clean and green hydrogen will contribute to transition towards a "low-carbon society" in Japan without handling CO_2 in Japan. But, we should remember that hydrogen importing needs enough hydrogen demand. If a VLCC continuously carries LOHC for hydrogen importing, over 2 billion Nm^3/yr (490 tpd) of hydrogen will be imported to Japan, and will require over 2 million FCVs to consume that amount of hydrogen. Spreading domestically produced hydrogen in Japan ahead of hydrogen importing is very important to create hydrogen demand in Japan. When hydrogen demand becomes large enough, hydrogen importing will start as LNG importing started in Japan 40 years ago.

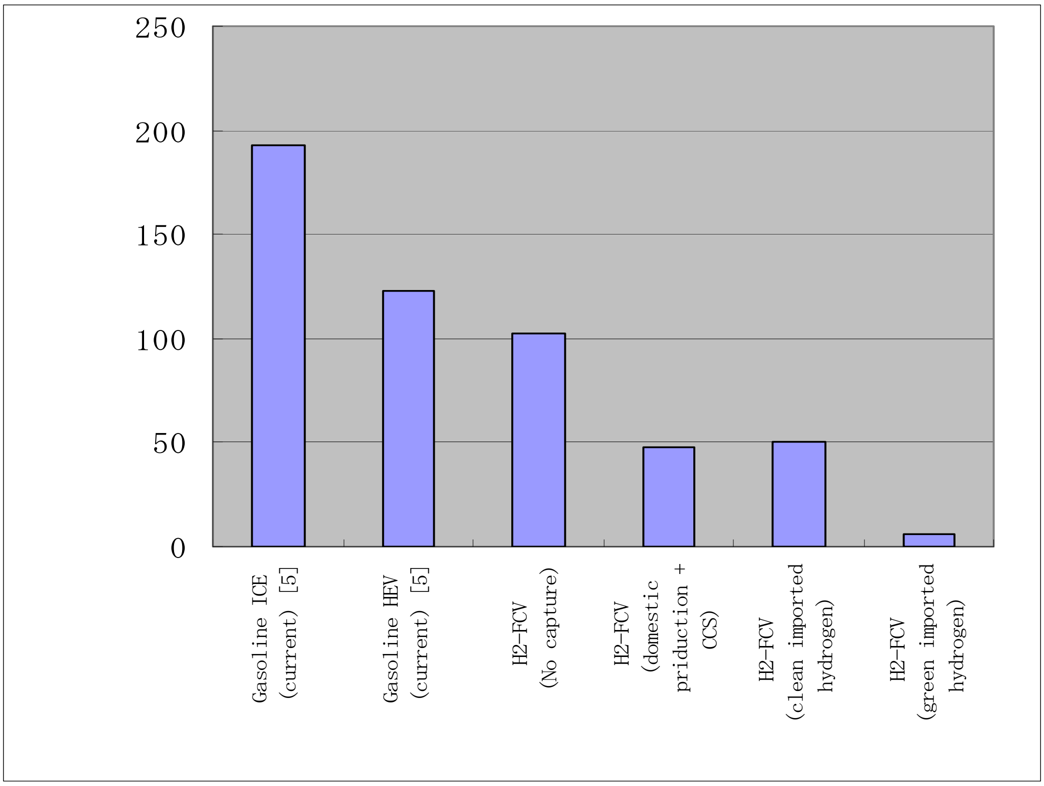

Figure 5: Well to Wheel CO_2 emission intensity of H_2-FCV comparison with gasoline vehicles.

4 Conclusion

In this paper we have explored the challenges and opportunities for the production and use of clean and green hydrogen for the Japanese transport sector. In this study, clean hydrogen is produced through natural gas reforming with CO_2 capture and storage (CCS), and green hydrogen is produced by wind power and water electrolysis. Four energy systems (clean hydrogen with LH_2, clean hydrogen with LOHC, green hydrogen with LH_2 and green hydrogen with LOHC) are compared in this study.

The hydrogen supply cost of clean hydrogen transported by LOHC is estimated as 6.5 $/kg and is positioned as the most economically reasonable energy system, while the CO_2 emission is 5.7 kg-CO_2/kg-H_2. The CO_2 emission intensity of green hydrogen transported by LH_2 is as low as 0.7 kg-CO_2/kg-H_2 and is positioned as the least CO_2 emission energy system, while the cost of hydrogen is estimated as 10.5 $/kg. The CO_2 avoidance cost of clean hydrogen transported by LOHC is estimated as 154 $/t-$CO_2$, and is similar to the CO_2 abatement cost of previous government's midterm target in Japan (-15% CO_2 reduction by 2020 comparing with 2005). This is an important finding as it shows that the cost importing of clean hydrogen is within the range of abatement costs that Japan is expected to face, and it thereby opens up opportunities for international clean energy trade which have so far been underexplored.

Using importing clean hydrogen as fuel for FCV, CO_2 emission will be around 1/4 comparing with gasoline ICE. Using importing green hydrogen, CO_2 emission will become less than 1/30. Considering importing hydrogen needs over 2 billion Nm^3 of hydrogen demand in a year (around 2 million FCVs is required to consume the hydrogen), starting from usage of domestically produced hydrogen, then importing clean hydrogen, and finally importing green hydrogen will be a realistic approach for realization of the hydrogen society in Japan.

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