Evaluation of the Economics of Renewable Hydrogen Supply in the APEC Region

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This paper presents the economics of renewable hydrogen in APEC region. With the cost reduction of renewable electricity, innovation of electrolyzer, hydrogen liquefier, storage, shipping, and other relevant technologies the fuel cost of imported renewable hydrogen for power generation was estimated to be JPY 51-69/Nm3 around 2030. To reach the government target (JPY 30/Nm3), acceleration of cost reduction over all the supply chain processes is required. Fuel cell vehicle hydrogen supply cost using domestic renewable electricity could be as low as 80JPY/Nm3 around 2030.

Keywords : Hydrogen, Renewable Energy, APEC

1. Background and purpose

Hydrogen is expected to contribute not only to decarbonizing the energy system, but also to improve energy security as it can be produced from diverse energy sources. When considering the supply of CO_2-free hydrogen to Japan from overseas, the APEC region, with its diverse energy resources, is expected to become a source of hydrogen. Importing hydrogen from APEC region will also help Japan to reduce its dependence on the Middle East for energy supply.

This study focuses on CO_2-free hydrogen produced by renewable energy (hereafter, "renewable"). By estimating the production cost of renewable hydrogen in major APEC economies. as well as the cost of transport and delivery of hydrogen, this study analyzes the economics of importing renewable hydrogen to Japan. It also compares the economics of imported renewable hydrogen with that produced by domestic renewable sources.

2. Method of evaluating the economics of renewable hydrogen supplies

2.1 Assumed hydrogen supply chain

Two supply routes of renewable hydrogen can be assumed: domestic production and import from overseas. The cost for domestic production of hydrogen consists of the cost for production and domestic delivery. The cost for imported hydrogen consists of the cost for production, transportation and storage cost in the producer economy, international transportation, use of receiving terminals, and domestic delivery.

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This study assumes that liquefied hydrogen, for which cost data are relatively accessible, is used as the energy carrier for hydrogen storage and international and domestic transportation and delivery, and that hydrogen pipelines are used for transportation of hydrogen in producer economies. Figure 1 shows the flow from the hydrogen production site to a hydrogen receiving terminal in Japan.

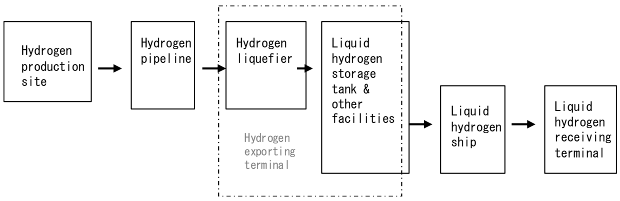

Figure 1 Hydrogen supply chain

2.2 Method of estimating costs

The costs in each phase of the hydrogen supply chain include CAPEX (initial investment), operation and maintenance (O&M) cost, and utility and feedstock cost (cost for electricity, water, etc.) The unit cost of hydrogen for each process is calculated using the equation:

Unit cost of hydrogen (yen/Nm^3) =levelized equipment cost + levelized O&M cost + levelized financing cost + utility and feedstock cost

The levelized cost is calculated as follows:

$$Levelized\ cost = \frac{Cost\ in\ present\ value}{\sum_{t=1}^{n} \frac{Annual\ amount\ of\ hydrogen}{(1 + Discount\ rate)^{(t-1)}}}$$

where n is the service life of the equipment.

Utility and feedstock cost is the cost of fuel (electricity) and feedstock (water) used in the process of producing, liquefying, and transporting hydrogen.

The cost for domestic terminals and transportation within Japan is derived from the result of existing study[1)].

3. Preconditions

3.1 Assumed renewable hydrogen producer economy

Based on the condition of renewable energy resources in the APEC region, the assumption on economies capable of supplying renewable hydrogen and the renewable technologies used for producing hydrogen is shown in Table 1.

Table 1 Renewable hydrogen producer economies and the renewable technologies used

	Wind power	Solar PV	Hydropower
Australia	•	•	
Canada			•
Chile		•	
China	•	•	•
Mexico	•	•	
New Zealand	•		•
Russia			•
United States	•	•	
Japan	•	•	

3.2 CAPEX, O&M cost, and financing cost

The CAPEX, O&M cost, and financing cost are assumed to be the same for all economies. Further, a reference scenario and a cost reduction scenario are assumed. The assumptions of the reference scenario described in References 1–5 are used as the reference scenario for this study. In the same references (Reference 1-5), if cost reduction measures are discussed, the results are used to the cost reduction scenario in this study. Financing cost and utility and feedstock cost are assumed to be the same for both scenarios.

(1) Electrolyzer

CAPEX assumption of electrolyzer is based on the polymert electrolyte membrane (PEM) electrolysis unit. The technical spec and cost assumptions for the large PEM water electrolysis unit, the values from a US DOE study (Hydrogen and Fuel Cells Program of the US Department of Energy (DOE)) are used[2)]. The values for the cost reduction scenario are also based on the low-cost scenario discussed in the same study (Reference [2)]).

Table 2 Major assumptions for the PEM water electrolysis unit

Item	Unit	Reference scenario	Cost reduction
Plant capacity	kg-H2/day	50,000	
Per-unit power consumption	kWh/kg-H2	50.2	45.0
Service life	year	20	
Initial investment	million US do	44	35
Operation & maintenance cost	%/equipment	8.5%	
Exchange rate	2015	121	

Source: Reference [2)], the World Bank, etc.

It is assumed that the entire renewable electricity output will be used for producing hydrogen. Thus, the cost of electricity supply for the water electrolysis will be the renewable power generation cost. Further, the utilization rate (=annual operation hours/8760 hours) of the water electrolysis unit will equal the capacity factor of the renewable power generation facility.

(2) Transportation, liquefaction, and storage of hydrogen

The technical specs for the hydrogen pipeline (including the compressor), hydrogen liquefier, exporting/receiving terminal, and liquid hydrogen ship are derived from the studies by the US DOE and the New Energy and Industrial Technology Development Organization (NEDO)[1–5)]. For electricity supply to the hydrogen pipeline, hydrogen liquefier, and exporting/receiving terminal, the use of grid electricity is assumed.

Table 3 Assumptions for the calculation of hydrogen transportation cost

Preconditions		Reference scenario	Cost reduction scenario
Hydrogen pipeline	Compressor capacity (kg-H2/day)	194,070	
	Number of compressors (units)	5	
	Pipeline length (km)	79	
	Compressor cost (million dollars/unit)	10	
	Pipeline cost (million dollars/km)	0.4	
	Annual operation & maintenance cost (%/total CAPEX)	8%	
	Electricity load (kW)	19,500	
Hydrogen liquefier	Liquefier capacity (kg-H2/day)	50,000	
	Number of liquefiers (units)	16	
	Liquefying efficiency (kWh/kg-H2)	6.4	
	Unit price of liquefier (million dollars/unit)	8	
	Annual operation & maintenance cost (%/total CAPEX)	3.6%	
Exporting terminal	Size of liquid hydrogen storage tank(m3/unit)	50,000	3.3 yen/Nm3
	Number of tanks (units)	4	
	Electricity load (kW)	6,000	
	Total initial investment (million dollars)	878	
	Annual operation & maintenance cost (%/total CAPEX)	1.9%	
Liquid hydrogen ship	Size Liquid hydrogen tank(m3/tank)	40,000	
	Number of tanks (tanks/ship)	4	
	BOG (Boil-off Gas) rate (%/day)	0.2%	
	Ship speed (km/h)	30	
	Number of days for cargo handling (loading/unloading total) (number of days)	4	
	Unit price (million dollars/ship)	413	
Receiving terminal (yen/Nm3)		8	4
Domestic delivery	To hydrogen power plant (yen/Nm3)	1.3	
	To hydrogen station (yen/Nm3)	3	

Source: Assumptions based on References 1–5

For the assumptions of the unit price of hydrogen exporting and receiving terminal in cost reduction scenario in this study, the result of the maximum reduction scenario till 2050 in Reference 1 is used.

(3) Financing cost

A discount rate of 5%, tax rate of 1.4%, 15-year depreciation period, and equity ratio of 100% are assumed. For the currency exchange, the average rate for 2015 is used.

3.3 Utility and feedstock cost

The mass production of renewable hydrogen is assumed to start around 2030, and thus, renewable power generation cost and the cost of the grid electricity consumed in the liquefaction, transportation, and storage of hydrogen are estimated for 2030.

Table 4 Estimated utility and feedstock costs

	Wind power		Solar PV		Hydropower		Water supply cost ($/m3)	Grid electricity supply cost ($/kWh)
	Generation cost ($/kWh)	Utilization rate	Generation cost ($/kWh)	Utilization rate	Generation cost ($/kWh)	Utilization rate		
Australia	0.049	30%	0.038	22%			1.50	0.095
Canada					0.034	54%	2.67	0.075
Chile	0.044	27%	0.027	25%			1.30	0.103
China	0.044	24%	0.029	17%	0.033	41%	0.61	0.092
Mexico	0.041	27%	0.031	22%			0.87	0.065
New Zealand	0.051	38%			0.034	52%	0.91	0.087
Russia					0.055	39%	0.42	0.020
United States	0.050	34%	0.030	21%			1.01	0.068
Japan	0.066	21%	0.058	15%			1.53	0.111

Source: Estimated based on References [6)–10)] and other materials

The cost of renewable power generation in the future is calculated based on the current CAPEX, O&M cost, capacity factor, and cost reduction trend in the future[6–8)]. For some economies, the generation cost is adjusted according to the announced electricity sales price. For Japan, the target price considered by the Renewable Energy Price Committee is used.

The cost of grid electricity is estimated based on the current level of electricity tariffs and the average generation cost in the future in each economy. The unit price of water for producing hydrogen is set by referring to the industrial water price of each economy.

4. Results

4.1 Reference scenario

(1) Hydrogen production cost

According to the results (Figure 2), hydrogen production using hydropower is less costly. If the generation cost of solar PV continues to decrease in the future, hydrogen production using solar PV could be cost competitive against hydropower in economies such as Chile, Mexico, and the US where solar radiation condition is good. The renewable hydrogen production cost of Japan is the highest in the APEC region.

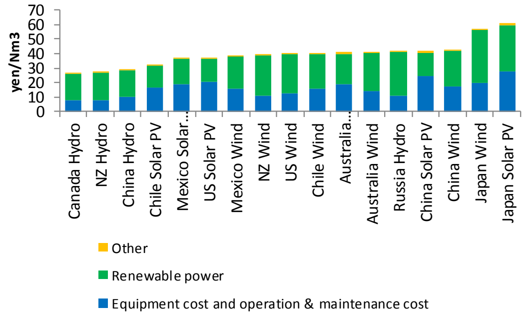

Figure 2 Renewable hydrogen production cost in selected APEC economies

(2) Supply cost of import renewable hydrogen

Figure 3 shows the supply cost of import renewable hydrogen for power generation in Japan.

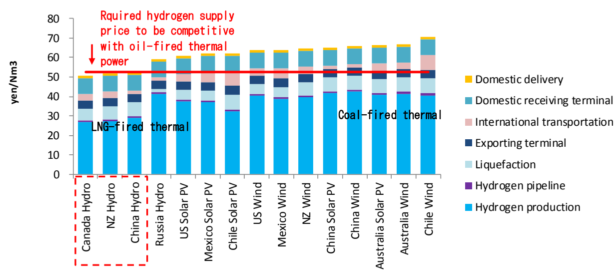

Figure 3 Supply cost of import renewable hydrogen for power generation

According to an existing study, the supply price of hydrogen required to make hydrogen power generation reach the same level as the oil-fired thermal power price in 2030 (38.5 yen/kWh) is estimated to be 52.6 yen/Nm^3 [4)]. As the supply cost of import renewable hydrogen will be 50.7–69.1 yen/Nm^3 (Figure 3), the sources of hydrogen that can meet the required price t will be limited to hydrogen produced by using hydropower in Canada, New Zealand, and China.

(3) Economics of domestic renewable hydrogen

The comparison of the supply cost of imported renewable hydrogen and domestic renewable hydrogen is conducted at the stage before the domestic delivery of hydrogen. That is, the production cost for domestic renewable hydrogen is compared with the cost of imported renewable hydrogen up to arrival at the domestic receiving terminal shown in Figure 3. It can be seen that domestic renewable hydrogen can be competitive with imported renewable hydrogen because for domestic produced hydrogen there is no cost for transportation, liquefaction, storage, and exporting terminal at the producing economy, as well as no cost for international transportation and receiving terminal (Figure 4).

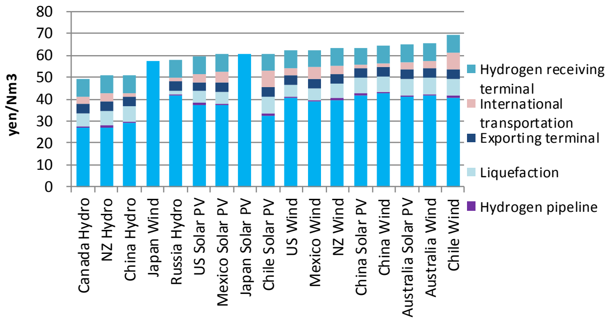

Figure 4 Cost comparison between domestic and imported renewable hydrogen

4.2 Cost reduction scenario

The economic viability of renewable hydrogen under the cost reduction scenario is discussed by looking at 2 cases: power generation, and domestic renewable hydrogen as fuel for fuel cell vehicles (FCVs).

(1) Imported renewable hydrogen for power generation

Figure 5 shows the supply cost of imported renewable hydrogen in the cost reduction scenario.

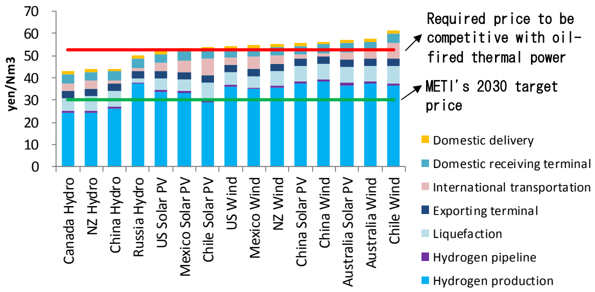

Figure 5 Imported hydrogen cost under the cost reduction scenario

In the cost reduction scenario, the sources of imported renewable hydrogen that can compete with oil-fired thermal power expanded to hydrogen produced using solar PV.

However, to achieve the target price of 30 yen/Nm^3 around 2030 set under the Strategic Road Map for Hydrogen and Fuel Cells of the Ministry of Economy, Trade and Industry[11)], further cost reduction is required over the whole the hydrogen supply chain.

(2) Domestic renewable hydrogen for fuel cell vehicles

The production cost of domestic renewable hydrogen is around 60 yen/Nm^3 under reference scenario (Figure 4) but can be reduced to around 51–55 yen/Nm^3 in the cost reduction scenario (Figure 6).

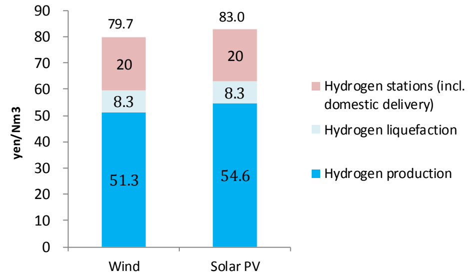

Figure 6 Cost of hydrogen supply for FCV using domestic renewable hydrogen (cost reduction effect included)

It is considered that the cost of hydrogen stations including domestic delivery can be reduced to approx. 20 yen/Nm^3 (with liquefied hydrogen as the hydrogen carrier) through economies of scale and the learning effect[1)]. Further, as the domestic hydrogen liquefaction cost will be 8.3 yen/Nm^3 (calculated based on the conditions in Tables 3 and 4), the supply cost of domestic renewable hydrogen as FCV fuel can be reduced to as low as 79.7 yen/Nm^3 (Figure 6).

5. Conclusion

The supply cost of imported renewable hydrogen to be used for domestic hydrogen power generation is considerably high even in 2030 (51–69 yen/Nm^3), and only the hydrogen produced from hydropower in Canada, New Zealand, or China can compete with oil-fired thermal power. The sources of hydrogen that can compete with oil-fired thermal power will expand to include solar PV-derived hydrogen if the cost of water electrolysis and hydrogen transportation is reduced. However, further cost reduction is required for imported renewable hydrogen to reach the government's target price of 30 yen/Nm^3.

On the other hand, the cost of domestic renewable hydrogen could be competitive with that of import renewable hydrogen. Driven by cost reduction of water electrolysis, the cost of domestic renewable hydrogen can be reduced to as low as 51 yen/Nm^3. If the cost of hydrogen stations is also reduced to the maximum extent, the hydrogen supply cost for FCV from domestic renewable hydrogen sources could be just under 80 yen/Nm^3.

This study compiles the results of parts of the joint study with the Asia Pacific Energy Research Centre (APERC).

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