Chapter 3

Review of Hydrogen Transport Cost and its Perspective (Liquid Organic Hydrogen Carrier)

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Chapter 3

Review of Hydrogen Transport Cost and its Perspective (Liquid Organic Hydrogen Carrier)

This chapter discusses hydrogen production and transportation cost in the global hydrogen supply chain utilising the liquid organic hydrogen carrier (LOHC) system.

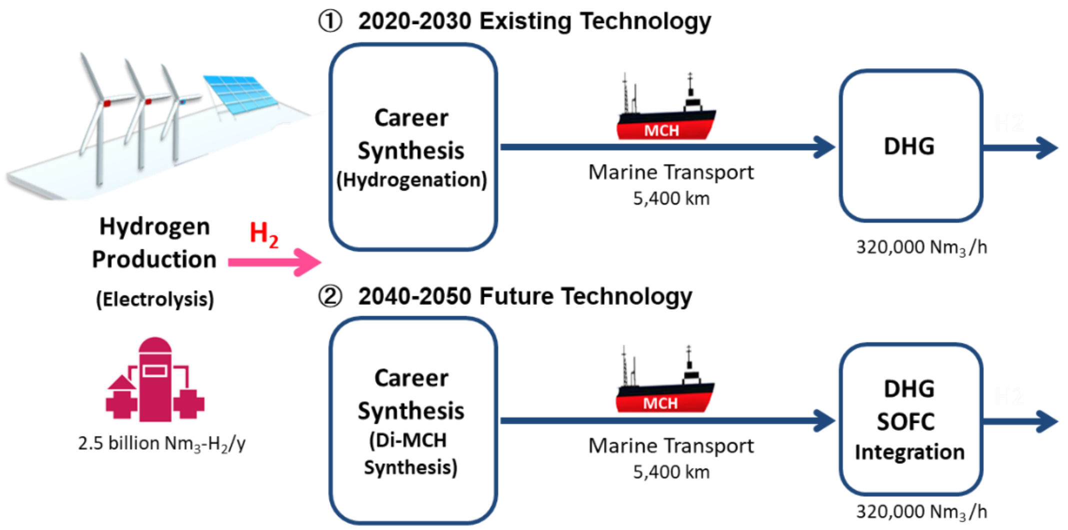
Various kinds of hydrogen carriers have been studied in LOHC system development activities so far, and this study focuses on methylcyclohexane (MCH) as a hydrogen carrier. In the MCH LOHC system, at the present status of technology, the resource hydrogen is chemically fixed to toluene in the hydrogenation reaction and converted into MCH. Then the MCH is stored and transported to hydrogen–demand countries in conventional chemical tanks and tankers in an ambient temperature and pressure, where hydrogen is extracted in dehydrogenation reaction for various uses in the industry, transport, commercial, and household sectors. This method is the combination of already proven existing technologies.

This study discusses the potential of reducing the cost of the MCH liquid organic hydrogen carrier system through future technology improvements and its impact on the overall supply chain cost.

1. Models of Global Hydrogen Supply Chain

Two global hydrogen supply chain models are proposed to compare the hydrogen costs: 2020–2030 Existing Technology model (Existing model) utilising existing technologies, and 2040–2050 Future Technology model (Future model) utilising future advanced technologies (Figure 3.1).

Figure 3.1: Models of Global Hydrogen Supply Chain



DHG = dehydrogenation, Di-MCH Synthesis = direct methylcyclohexane synthesis, SOFC = solid oxide fuel cell.
Source: Author.

The chain starts from the renewable energy power to produce resource hydrogen. The hydrogen capacity is set at 320,000 Nm3/h H2, which corresponds to 2.5 billion Nm3/y H2; transportation distance is assumed to be 5,400 km in both models. The advanced technologies employed for the Future model are listed as follows.

Future technologies:

- ✓ Process simplification, such as MCH direct synthesis (Tokyo University, 2019), employed as a substitute for the combination of electrolysis and hydrogenation (HGN)
- ✓ Transportation efficiency Improvement utilising Super Eco Ship (NYK)
- ✓ Energy efficiency improvement of dehydrogenation by catalyst performance increase
- ✓ Heat integration optimisation using SOFC exhaust gas to dehydrogenation heat

2. Key Assumptions

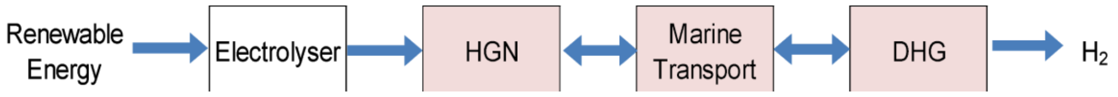
The block flows of two supply chain models are illustrated in Figure 3.2 and the key assumptions are shown in Table 3.1 to estimate the hydrogen supply chain cost in both models.

In the 2020–2030 Existing Technology model (Existing model), hydrogen is produced from renewable power by polymer electrode membrane (PEM) electrolysis and chemically fixed to toluene in the hydrogenation reaction. Then the produced MCH is transported by sea through conventional chemical tankers to hydrogen-demand countries. The hydrogen is extracted from the MCH by dehydrogenation reaction.

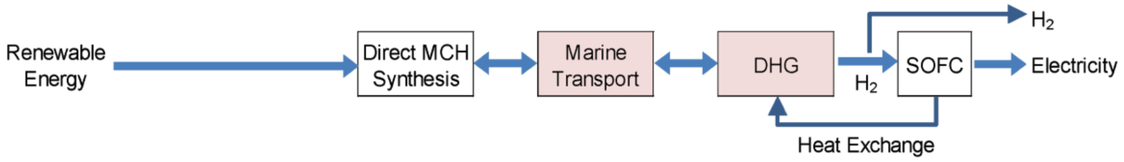
In the 2040–2050 Future Technology model (Future model), renewable power will directly synthesise MCH from toluene and water and MCH will be transported by the Super Eco Ships to hydrogen-demand countries, where hydrogen will be extracted in the dehydrogenation reaction to be fuelled for solid oxide fuel cell (SOFC) power generation. SOFC exhaust heat will also be used for dehydrogenation reaction to further reduce costs.

Figure 3.2. Block Flows for Two Supply Chain Models

1 2020–2030 Existing Technology



2 2040–2050 Future Technology



HGN = hydrogenation, DHG = dehydrogenation, SOFC = solid oxide fuel cell.
Source: Author.

Table 3.1: Key Assumptions for Cost Calculation

Contents	① Existing Technology	② Future Technology
Renewable energy	Capacity factor 70% (Hybrid of wind and solar power + battery) (Steggel et al., 2018)	
Hydrogen capacity	2.5 billion Nm3 /y Hydrogen	
Hydrogen production	PEM water electrolysis Efficiency: 5.0 kWh/Nm3 (Element energy 2018)	—
Carrier synthesis	Hydrogenation	Direct MCH synthesis
Marine transport	5,400 km Chemical tanker	5,400 km Super Eco Ship (NYK)
Hydrogen extraction	Dehydrogenation	
Heat integration	—	SOFC exhaust gas for dehydrogenation SOFC efficiency: 50% (Mizutani, 2019)
Commercial conditions	Project period: 20 years Full equity base	

MCH = methylcyclohexane, PEM = polymer electrode membrane, SOFC = solid oxide fuel cell.
Source: Author.

3. Global Hydrogen Supply Chain Cost

The global hydrogen supply chain costs are compared between the Existing and Future models.

Because of improvements in catalyst performance, such as impurity reduction and longevity extension, and heat integration of SOFC exhaust gas to dehydrogenation reaction, the cost of dehydrogenation could be reduced by nearly 40% in 2040–2050.

The use of the Super Eco Ship (NYK) could also contribute to reduce the cost of marine transport by nearly 10%.

The cost reduction effect of the simplification process in carrier synthesis and employment of MCH direct synthesis to substitute for electrolysis and hydrogenation will vary depending on electricity prices.

3.1. Hydrogen cost comparison (electricity US$0.05/kWh)

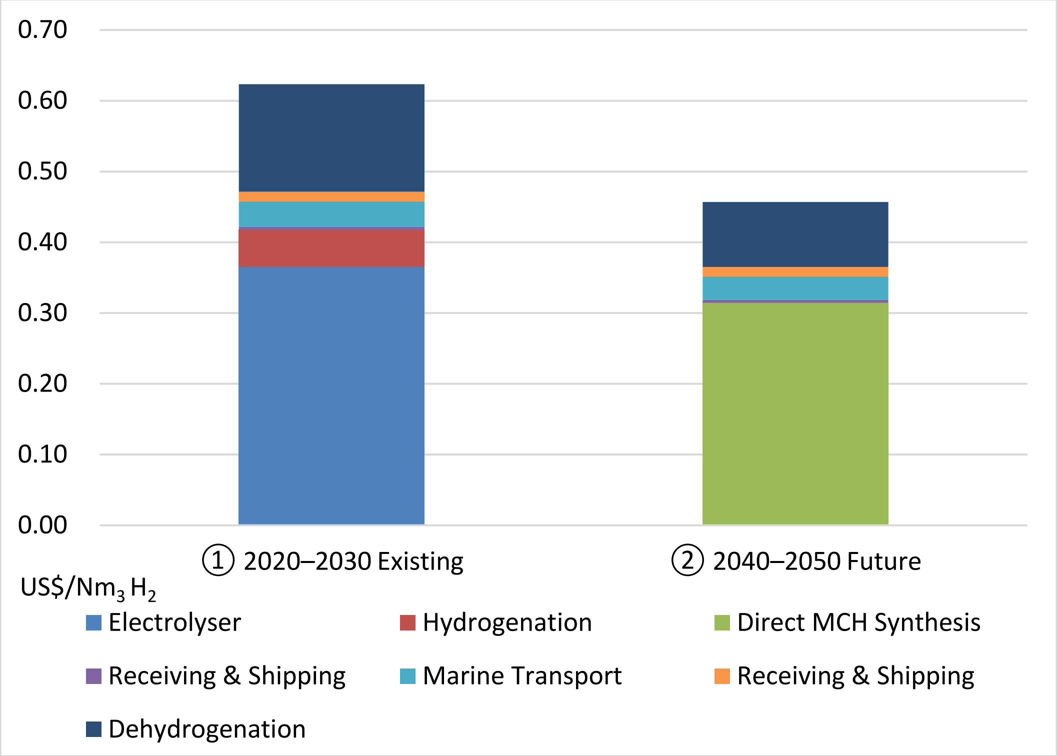
The cost projection results between the Existing and Future models were compared. At the electricity price of US$0.05/kWh, the hydrogen price in 2040–2050 is estimated to be reduced by around 25%, compared to US$0.62/Nm3 in 2020–2030.

Due to the high electricity price for electrolysis, carrier synthesis, PEM electrolysis plus hydrogenation or direct MCH synthesis account for nearly 70% of the hydrogen costs in both models.

In the Future model, the cost of direct MCH synthesis accounts for around 70% of the total, followed by dehydrogenation at 20%, and marine transportation, 7%.

The cost of carrier synthesis is projected to be reduced by 25% in the Future model, compared to the Existing model.

Figure 3.3: Hydrogen Cost Comparison (Distance: 5,400 km; Electricity US$0.05/kWh)



Note: The data ① were customised based on Institute of Applied Energy (2016).
Source: Authors' analysis based on Institute of Applied Energy (IAE) Report.

3.2. Hydrogen cost comparison (electricity US$0.03/kWh)

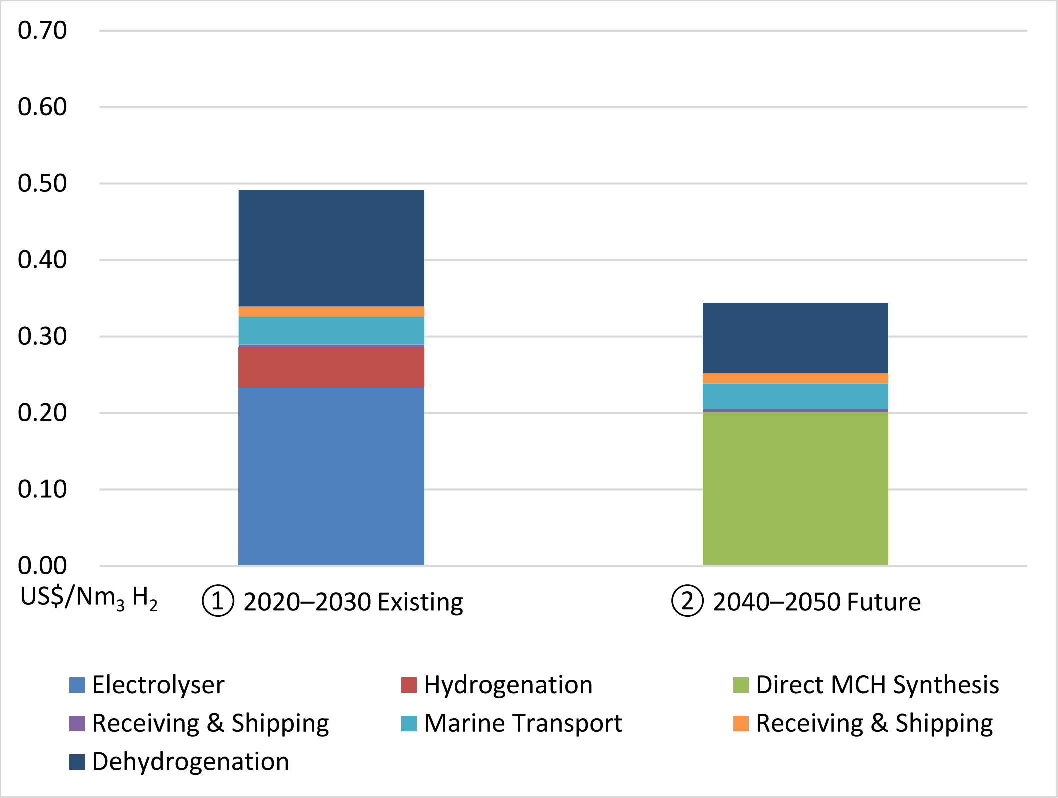
At the electricity price of US$0.03/kWh, the hydrogen price is projected to be reduced by nearly 30% by 2040–2050 compared to US$0.49/Nm3 in 2020–2030.

Carrier synthesis, PEM electrolysis + hydrogenation or direct MCH synthesis, account for nearly 60% of the hydrogen costs in both models.

The same as the electricity price of US$0.05/kWh case, direct MCH synthesis shares the largest part of the supply chain costs, accounting for around 60%, followed by dehydrogenation at 27%, and marine transport at 10% in the Future model.

The cost of carrier synthesis is projected to be reduced by around 70% in 2040–2050, compared to that of the Existing model.

Figure 3.4: Hydrogen Cost Comparison (Distance: 5,400 km; Electricity US$0.03/kWh)



Note: The data ① were customised based on Institute of Applied Energy (2016).
Source: Authors' analysis based on Institute of Applied Energy (IAE) Report.

3.3. Hydrogen cost comparison (electricity at US$0.01/kWh)

At the electricity price of US$0.01/kWh, the hydrogen cost will be significantly reduced due to the low electricity prices in both models.

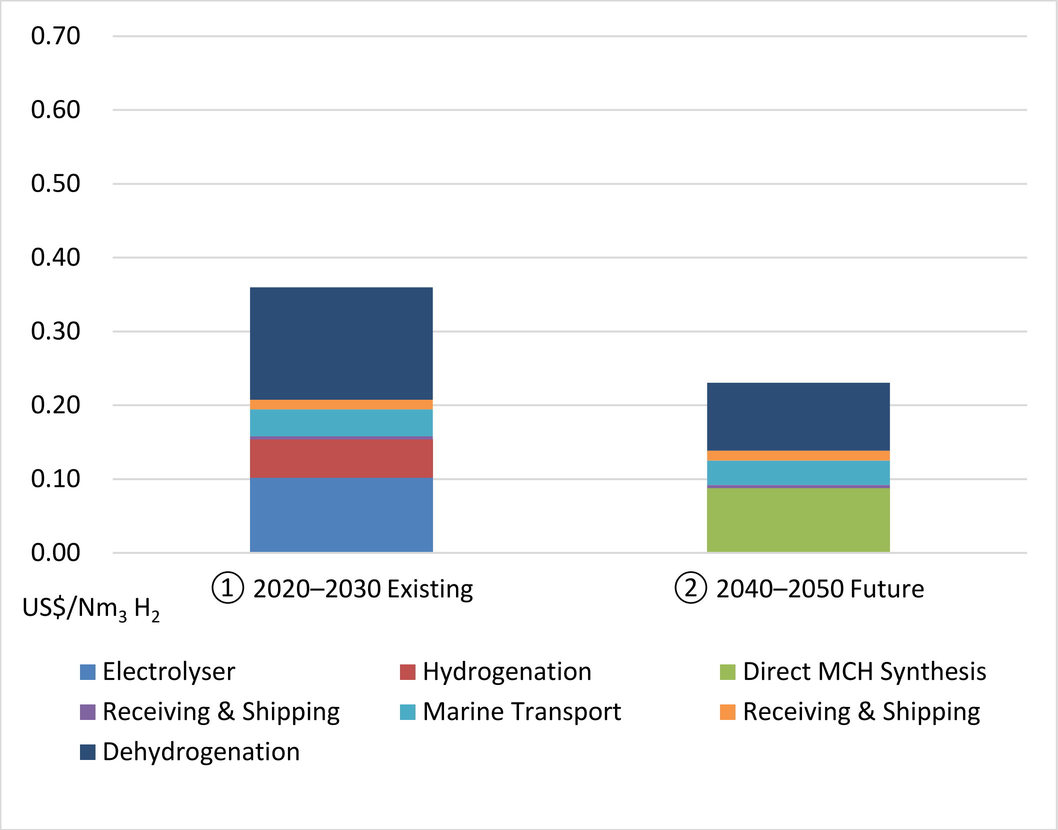
In the Future model, the supply chain cost could be reduced to around US$0.23/Nm3, nearly a 35% reduction from that of the Existing model.

Thanks to the low electricity prices, cost sharing of carrier synthesis in the total supply chain costs will be largely reduced in both models in this electricity price level, accounting for around 40%.

In the Future model, unlike the previous two electricity price cases, dehydrogenation shares the largest portion of the costs, accounting for 40%, followed by direct MCH synthesis at 38%, and marine transport at 14%.

The cost of carrier synthesis will be reduced by around 40% in 2040–2050 compared to that of the Existing model.

Figure 3.5: Hydrogen Cost Comparison (Distance: 5,400 km; Electricity at US$0.01/kWh)



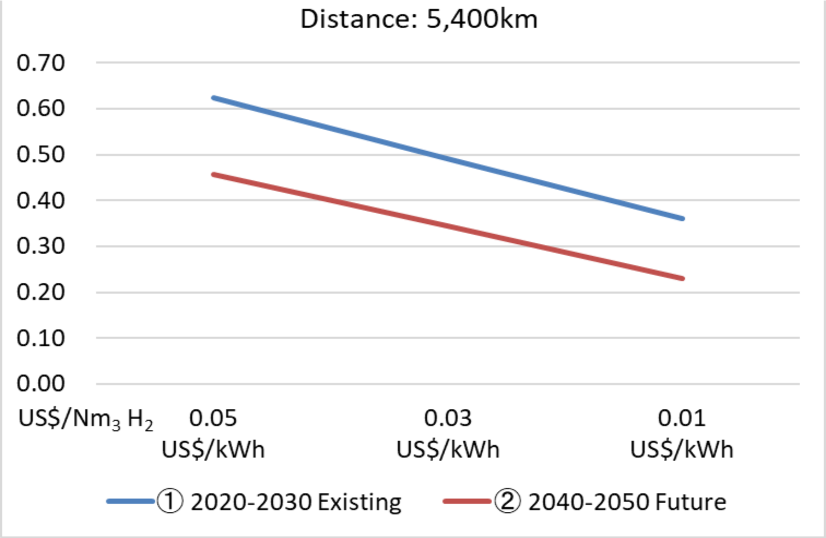
Note: The data ① were customised based on Institute of Applied Energy (2016).
Source: Authors' analysis based on Institute of Applied Energy (IAE) Report.

3.4. Sensitivity analysis

Sensitivity analysis is performed on hydrogen supply chain cost based on electricity prices. As illustrated so far, the hydrogen costs will be highly dependent on electricity prices. As the electricity prices decrease from US$0.05/kWh to US$0.01/kWh, the hydrogen costs are reduced by around 50% in both models.

The hydrogen cost is estimated to reach around US$0.62/Nm3 at US$0.05/kWh in the Existing model at its highest, and US$0.23/Nm3 at US$0.01/kWh in the Future model at its lowest. It shows an almost 60% reduction of the overall supply chain cost.

Figure 3.6: Sensitivity to Electricity Prices



Note: The data ① were customised based on Institute of Applied Energy (2016).
Source: Author (2020).

4. Conclusion

This section investigated the global hydrogen supply chain cost of two models, the 2020–2030 Existing Technology model (Existing model) and the 2040–2050 Future Technology model (Future model).

The study showed that the total hydrogen supply chain cost could be reduced by around 20%–30% broadly owing to future technology improvements, like MCH direct synthesis, catalyst performance upgrades, and heat integration of SOFC exhaust gas to dehydrogenation reaction.

At the electricity price of US$0.01/kWh in the Future model, hydrogen supply cost will be most competitive at US$0.24/Nm3. At the electricity price of US$0.05/kWh in the Existing model, hydrogen supply cost is highest at US$0.60/Nm3.

From the study, we can conclude that, starting from renewable power–derived hydrogen, the hydrogen supply chain cost is highly dependent on electricity prices in hydrogen-supplier countries. Electricity prices directly influence the cost of carrier synthesis in both models, the PEM electrolysis plus hydrogenation in the Existing model, or direct MCH synthesis in the Future model, and the prices significantly impact the overall supply chain costs.