

IEEJ Webinar The Economics of the Green Hydrogen International Supply Chain

The Institute of Energy Economics, Japan (IEEJ) Yoshiaki SHIBATA, • Sichao KAN, Masato YOSHIDA, Hiroko NAKAMURA, Toshiyuki SAKAMOTO





(I) Background & Objectives

(2) Methodology & Assumptions

(3) Major Findings

(4) Implications

Background & Objectives



- For Japan to achieve carbon neutrality by 2050, import of clean hydrogen from overseas will be necessary.
- Blue hydrogen, though cheaper today, has higher carbon footprint than green hydrogen. Besides, blue hydrogen also has other risks such as increasing pressure on divestment of fossil fuel assets, etc.. In this sense, green hydrogen is one of the important options for future clean energy supply.
- Furthermore, resource countries of green hydrogen is more diversified than that of blue hydrogen, which will also contribute to Japan's energy security.

This study reveals the costs and carbon footprint across the whole green and blue hydrogen supply chains from potential suppliers to Japan.

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Cases







| Liquefied Hydrogen (LH₂)
| Methylcyclohexane (MCH)
| Ammonia (NH₃)

Source for map:https://www.stat.go.jp/data/sekai/pdf/worldmap.pdf





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Methodology: Hydrogen Supply





Methodology: Blue NH₃ from Natural Gas



Since the process of NH₃ production from natural gas is already a mature and widely-used technology, the study assumes hydrogen production and NH₃ production are integrated in the case of blue NH₃ production from natural gas.



Methodology: Flow for GHG Emission Estimation



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Major Assumptions (1)



- 225,000 ton annual hydrogen production (annual hydrogen consumption for I GW scale hydrogen power generation plant)
- *** 2030** as reference year
- CAPEX, OPEX, conversion efficiency, and other technical spec assumptions based on studies from IEA (Future of Hydrogen) and Applied Energy Institute, etc.

Two cases for Electrolyzer CAPEX (2030)



Major Assumptions (2)

Assumptions on renewable LCOE, capacity factor, fossil fuel prices, etc. were made based on published research reports.

Assumptions on RE LCOE and Capacity Factor (2030)

Fossil Fuel Price (2030)





Major Assumptions (3)



International Shipping Routes



Major Assumptions (4)

390% carbon capture rates for bule hydrogen/NH₃ (IEA)

US EPA's report* is the reference for the estimation of fossil fuel upstream GHG emission factor

Assumptions on Fossil Fuel's Upstream GHG **Emission Factor**



* United States Environmental Protection Agency, Inventory of U.S. Greenhouse Gas Emissions and Sinks 1990-2019

Assumptions on Grid CO₂ Emission Factor (2030)

| Resource Country | Emission Factor (kg-CO ₂ /kWh) |
|------------------|--|
| Australia | 0.40 |
| Chile | 0.10 |
| Saudi Arabia | 0.30 |
| United States | 0.27 |

* Grid CO₂ emission factors were estimated based on the countries' 2030 power generation mixes published by the governments.





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Major Findings: Hydrogen Production Cost





Hydrogen Production Cost (2030)

If electrolyzer's CAPEX could be reduced to around 1/3 of today's level (900USD/kW) by 2030, green hydrogen production cost in countries such as Chile or Australia can be cheaper than blue hydrogen.

Major Findings: Hydrogen Import Cost



Green hydrogen from Chile has the lowest cost when the hydrogen carrier is liquefied hydrogen or MCH.
However, when the hydrogen carrier is ammonia, blue hydrogen (produced with natural gas + CCS) is the cheapest.

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Major Findings: Carbon Footprint



- * For hydrogen production, carbon footprint of green hydrogen is much lower than that of blue hydrogen.
- However, if electricity input for hydrogen conversion, transportation, and storage is from the grid (which is the assumption for this study), hydrogen supply chain from countries with lower grid CO₂ emission factor, such as Chile, will has lower carbon footprint.
- Among the hydrogen carriers, liquefied hydrogen has the lowest carbon footprint because shipping fuel is also liquefied hydrogen, liquefied hydrogen supply chain needs no reconversion,.
- * For ammonia, if it is used directly (means no reconversion needed) the supply chain's carbon footprint will be lower.

Major Findings: Impact of Carbon Price (assuming 100USD/CO₂ carbon price)



- If hydrogen carrier is liquefied hydrogen or MCH, in the Low Electrolyzer Cost Case the import cost of green hydrogen from Chile can be competitive with blue hydrogen from Saudi Arabia.
- However, when the hydrogen carrier is ammonia, blue hydrogen from Saudi Arabia still has cost advantage.

Major Findings: Ammonia Direct Use

Unit Converted to \$/kg-H₂



If ammonia is used directly as fuel (no reconversion needed), blue ammonia from natural gas (from Australia or Saudi Arabia natural gas) has the lowest cost.

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Unit of \$/t-NH₃

Major Findings: Ammonia Direct Use (carbon price: 100USD/t-CO₂)

AUS CoalCCS **AUS CoalCCS** 309 1.7 4.1 729 Blue Blue AUS GasCCS AUS GasCCS 2.0 **13** 2.8 355 **498** Saudi_GasCCS Saudi_GasCCS 264 1.5 **B** 2.2 7 400 US PV 2.8 US PV 497 830 **3** 4.7 US Wind 2.5 US Wind 4.3 437 770 Green (Base) Green (Base) AUS Wind **AUS Wind** 2.3 4.4 416 789 AUS_PV AUS PV 2.1 4.2 380 752 Chile PV 2.0 Chile PV 356 0.1 3.8 26 668 Chile Wind Chile Wind 1.6 289 3.4 6 601 US_PV US_PV 2.1 4.0 371 704 (Low ELY Cost) (Low ELY Cost) US_Wind US_Wind 346 1.9 3.8 679 Green Green AUS_Wind AUS Wind 1.9 4.0 336 709 AUS_PV AUS_PV 1.5 3.6 264 636 Chile_PV Chile_PV 0.13.1239 6 551 1.3 Chile_Wind Chile_Wind 1.3 0.13.1\$/kg-H2 231 6 543 \$/t-NH3 0.0 2.0 3.0 4.0 5.0 6.0 7.0 0 200 400 600 800 1000 1.0 1200 Production Compressor & Pipeline ■ Conversion Export terminal Shipping Import terminal Carbon cost

Unit Converted to \$/kg-H₂

Even with a carbon price of 100USD/t-CO₂, the cost advantage of blue ammonia from natural gas (from Australia or Saudi Arabia) can still be maintained.

Unit of \$/t-NH₃





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Uncertainties



It should be noted that there are uncertainties in the assumptions made in this study:

- Blue hydrogen/ammonia is assumed to be produced with an additional cost for CCS with a carbon capture rate of 90%. However, in the case of blue ammonia, the current carbon capture rate for the entire blue ammonia production from gas is, in general, 50% to 60%. If a carbon capture rate of 90% is sought for all blue ammonia production, costs could be higher.
- In terms of green ammonia production, this study assumes the same process as blue ammonia production from gas. However, to maintain the large-scale and constant operation assumed for this process additional equipment such as buffer tank will be needed to cope with variable input (since the hydrogen for ammonia production is produced with variable RE).
- Assumptions of this study were made based on best available data when the report was published. However, the technologies associated with hydrogen supply chain are evolving very fast and how to reflect the up-to-date technology development in the calculation will be an issue for future analysis.

Implications



Cost Reduction of Green Hydrogen Supply Chain

- Green hydrogen from Chile has the lowest cost among the green hydrogen options. Green hydrogen could be cheaper than blue hydrogen by 2030 with electrolyzer's CAPEX be lowered to 1/3 of today's level (900USD/kW).
- ☆ To achieve the hydrogen price target set by the Japanese Government (30JPY/Nm³(≒3.1USD/kg-H₂) by 2030, 20JPY/Nm³(≒2.1USD/kg-H₂) by 2050), besides continued efforts on R&D of liquefied hydrogen and MCH, measures for production cost reduction of green hydrogen in the resource countries will be needed.
- Some of the green hydrogen production cost reduction measures include:
 - \checkmark Smoothed power input to electrolyzer from a combination of solar PV and wind
 - ✓ R&D on electrolyzer's cost reduction
 - Scaling-up market for green hydrogen applications including markets in resource countries. For example, market for utilizing green hydrogen for grid balancing
- Cooperation between Japan and resource countries is necessary
 - Supporting resource countries on developing hydrogen strategy/roadmap, which can help encouraging more investment to green hydrogen
 - \checkmark Sharing know-hows with resource countries on domestic hydrogen supply infrastructure
 - ✓ Cooperation with resource countries on hydrogen export infrastructures, e.g. ports, etc.
 - ✓ Cooperation on international certifications / standards for hydrogen supply chain's carbon footprint evaluation

Implications



Other Implications: Energy Security

- Import of green hydrogen from countries in the Asia-Pacific region such as Chile will contribute to Japan's energy security because of the diversification of energy supply sources.
- Though there may be concerns that long distance between Chile and Japan would result in high shipping cost of hydrogen, the results of the study suggest that long shipping distance's impact on the overall hydrogen import cost is actually quite limited.



Thanks for your time and attention.

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Contact:report@tky.ieej.or.jp