IEEJ Webinar for the World

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

Outline

(1) 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.

Cases

Solar PV

Wind

Natural gas + CCS

Brown coal + CCS

| Liquefied Hydrogen (LH_2)

| Methylcyclohexane (MCH)

| Ammonia (NH_3)

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

Outline

(1) Background & Objectives

(2) Methodology & Assumptions

(3) Major Findings

(4) Implications

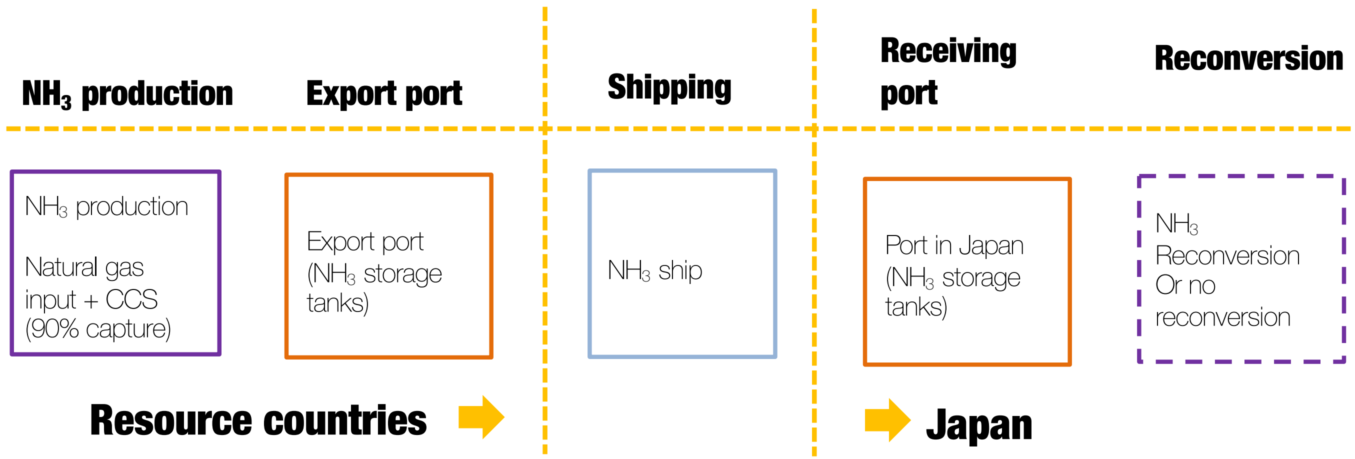
Methodology: Hydrogen Supply

	Hydrogen production	Hydrogen pipeline	Conversion	Export port	Shipping	Receiving port	Recoversion
Blue H_2	Natural gas reforming + CCS Brown coal gasification + CCS	Assume 100km pipeline distance for all cases	Liquefaction	Export port (Liquified hydrogen storage tanks)	Liquified H_2 ship	Port in Japan (Liquified hydrogen storage tanks)	
			H_2+Toluene-> MCH	Export port (Toluene storage tanks)	MCH ship	Port in Japan (Toluene storage tanks)	MCH Reconversion
Green H_2	Water electrolysis with Solar PV or Wind power		Haber-Bosch: green H_2 or H_2 from brown coal CCS	Export port (NH_3 storage tanks)	NH_3 ship	Port in Japan (NH_3 storage tanks)	NH_3 Reconversion Or no reconversion

Resource countries ➡ | ➡ **Japan**

Methodology: Blue NH_3 from Natural Gas

- Since the process of NH_3 production from natural gas is already a mature and widely-used technology, the study assumes hydrogen production and NH_3 production are integrated in the case of blue NH_3 production from natural gas.



Methodology: Flow for GHG Emission Estimation

	Upstream	Hydrogen	Hydrogen pipeline	Conversion and export port	Shipping	Receiving port	Recoversion
Blue H_2	Fossil fuel exploration, production, processing	H_2 production (+CCS) Natural gas/coal + carbon capture rate: 90%	H_2 compression & pipeline (Grid electricity)	Liquefaction (Grid electricity)	Using H_2 as shipping fuel (Blue/Green H_2 emission factor)	Port in Japan (Grid electricity)	
				Hydrogen + Toluene -> MCH (Grid electricity, natural gas)	Fuel for shipping: Very low sulfur fuel oil (VLSFO)	Port in Japan (Grid electricity)	MCH-> Hydrogen + Toluene (Natural gas, Grid electricity)
Green H_2	No GHG emission for RE power generation	No GHG emission		• NH_3 production from H_2 (Grid electricity) • NH3 production from natural gas (Natural gas)	Fuel for shipping: Very low sulfur fuel oil (VLSFO)	Port in Japan (Grid electricity)	NH_3->Hydrogen + Nitrogen (Natural gas, Grid electricity)

Resource countries → | → Japan

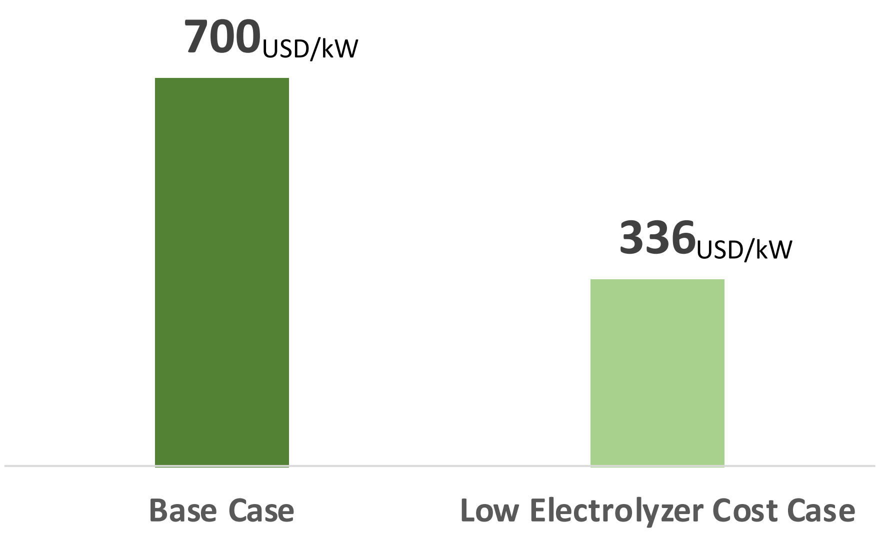
Major Assumptions (1)

❖ **225,000 ton** annual hydrogen production (annual hydrogen consumption for 1 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.

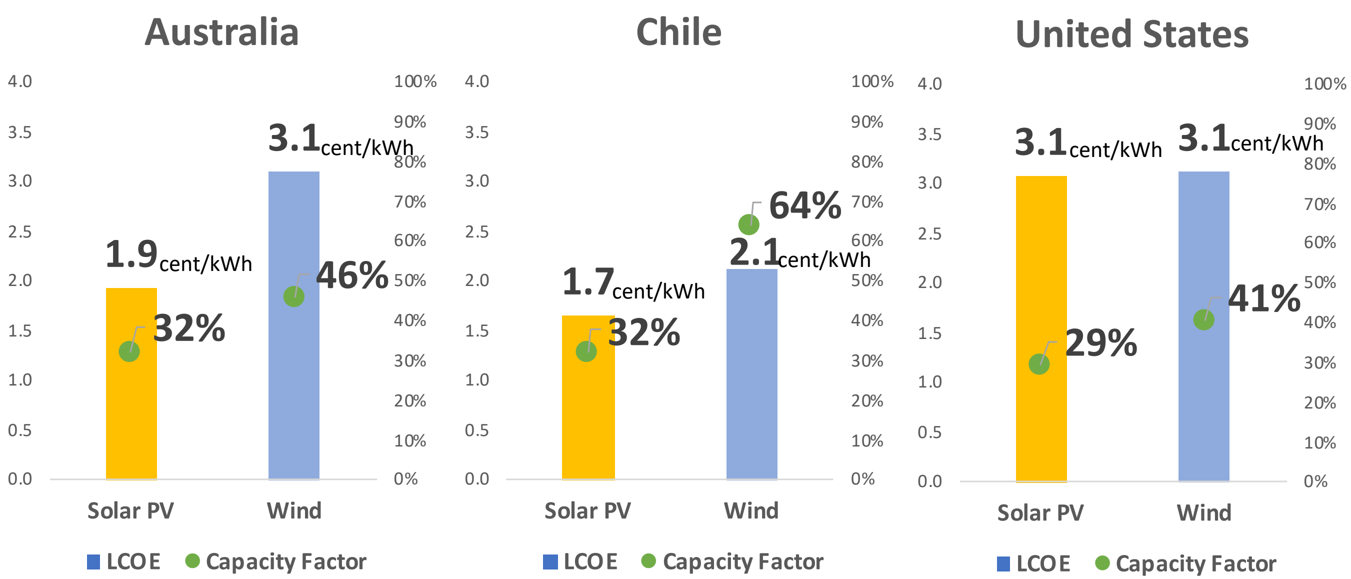
Two cases for Electrolyzer CAPEX (2030)



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)

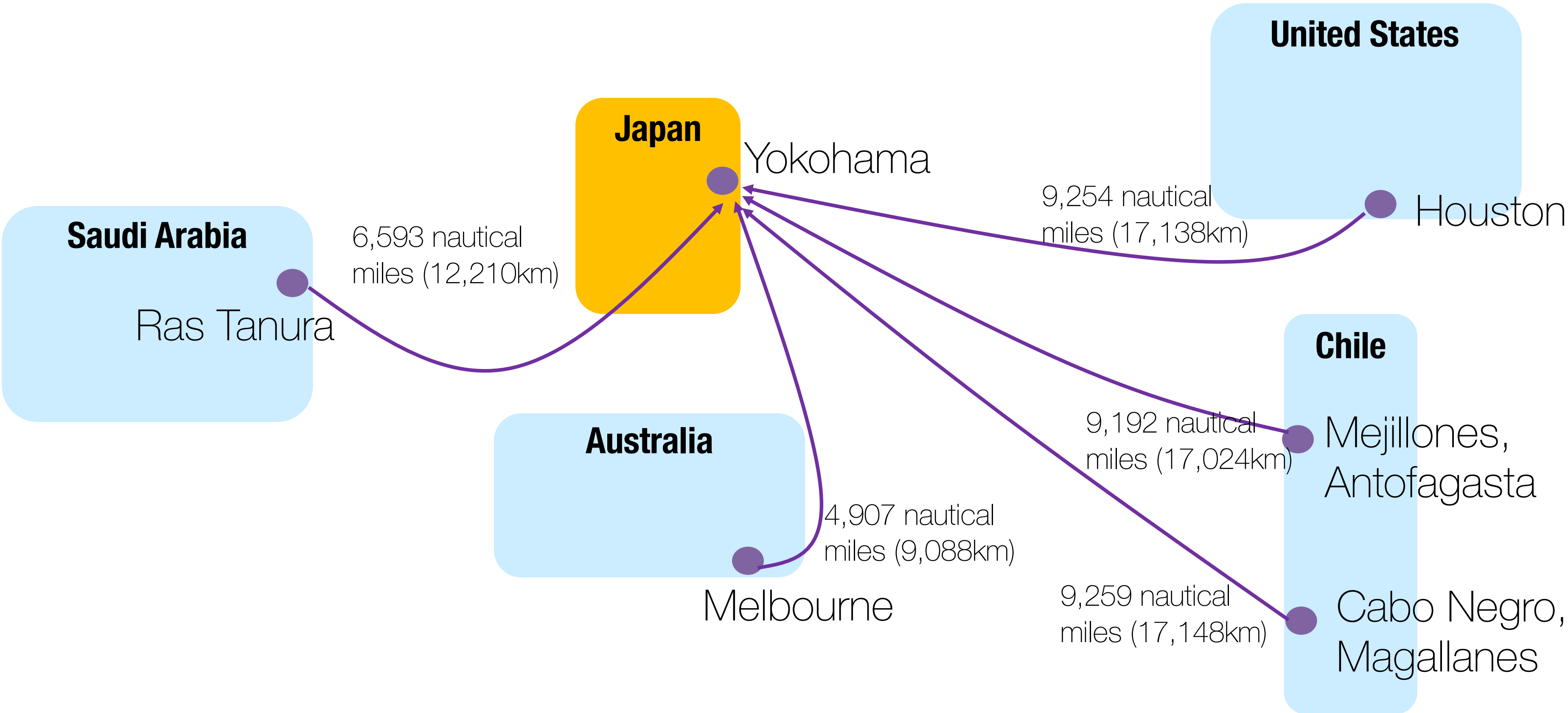


Fossil Fuel Price (2030)

	Australia	Saudi Arabia
Gas (USD/mmbtu)	6.2	4
Coal (USD/ton)	16.2	-

Major Assumptions (3)

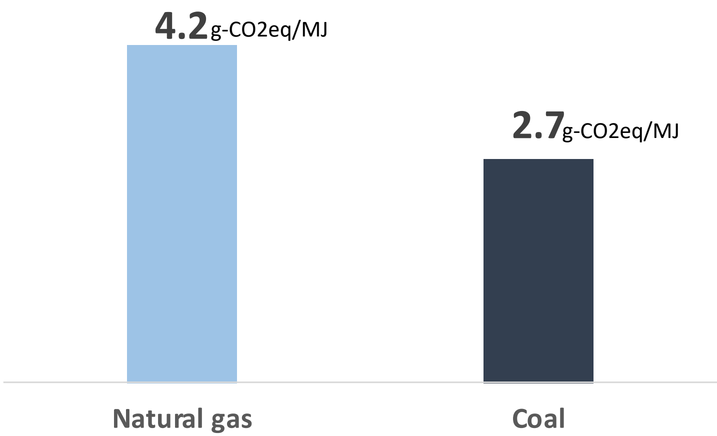
International Shipping Routes



Major Assumptions (4)

- **90%** carbon capture rates for bule hydrogen/NH_3 (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 CO_2 Emission Factor (2030)

Resource Country	Emission Factor ($kg\text{-}CO_2/kWh$)
Australia	0.40
Chile	0.10
Saudi Arabia	0.30
United States	0.27

* Grid CO_2 emission factors were estimated based on the countries' 2030 power generation mixes published by the governments.

Outline

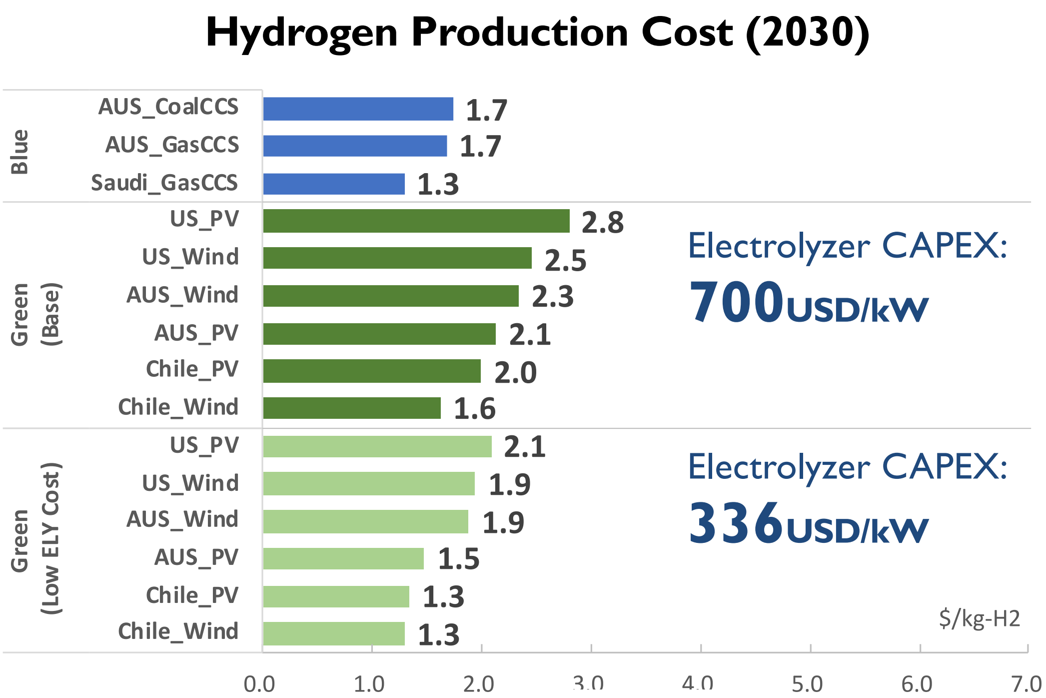
(1) Background & Objectives

(2) Methodology & Assumptions

(3) Major Findings

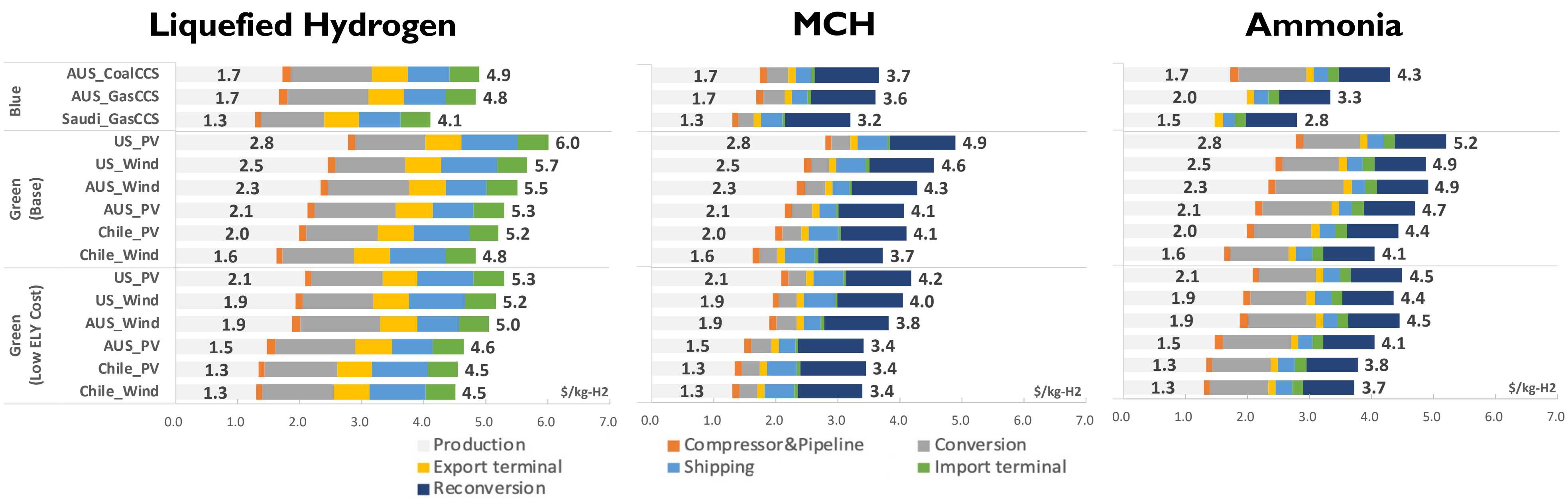
(4) Implications

Major Findings: Hydrogen Production Cost



❖ 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.

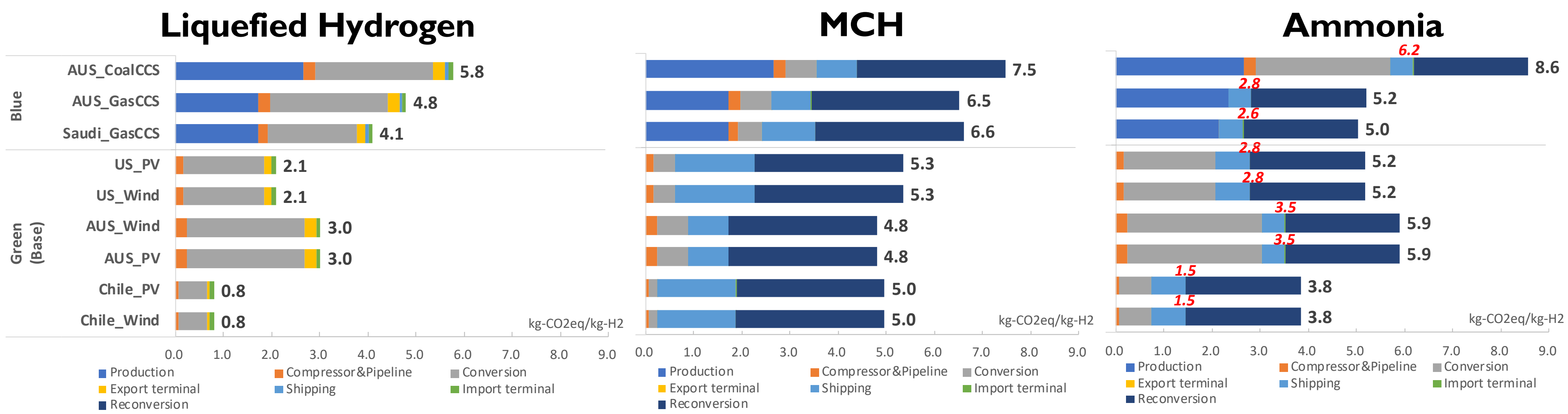
Major Findings: Hydrogen Import Cost



	Liquefied Hydrogen (Production / Total)	MCH (Production / Total)	Ammonia (Production / Total)
Blue – AUS_CoalCCS	1.7 / 4.9	1.7 / 3.7	1.7 / 4.3
Blue – AUS_GasCCS	1.7 / 4.8	1.7 / 3.6	2.0 / 3.3
Blue – Saudi_GasCCS	1.3 / 4.1	1.3 / 3.2	1.5 / 2.8
Green (Base) – US_PV	2.8 / 6.0	2.8 / 4.9	2.8 / 5.2
Green (Base) – US_Wind	2.5 / 5.7	2.5 / 4.6	2.5 / 4.9
Green (Base) – AUS_Wind	2.3 / 5.5	2.3 / 4.3	2.3 / 4.9
Green (Base) – AUS_PV	2.1 / 5.3	2.1 / 4.1	2.1 / 4.7
Green (Base) – Chile_PV	2.0 / 5.2	2.0 / 4.1	2.0 / 4.4
Green (Base) – Chile_Wind	1.6 / 4.8	1.6 / 3.7	1.6 / 4.1
Green (Low ELY Cost) – US_PV	2.1 / 5.3	2.1 / 4.2	2.1 / 4.5
Green (Low ELY Cost) – US_Wind	1.9 / 5.2	1.9 / 4.0	1.9 / 4.4
Green (Low ELY Cost) – AUS_Wind	1.9 / 5.0	1.9 / 3.8	1.9 / 4.5
Green (Low ELY Cost) – AUS_PV	1.5 / 4.6	1.5 / 3.4	1.5 / 4.1
Green (Low ELY Cost) – Chile_PV	1.3 / 4.5	1.3 / 3.4	1.3 / 3.8
Green (Low ELY Cost) – Chile_Wind	1.3 / 4.5	1.3 / 3.4	1.3 / 3.7

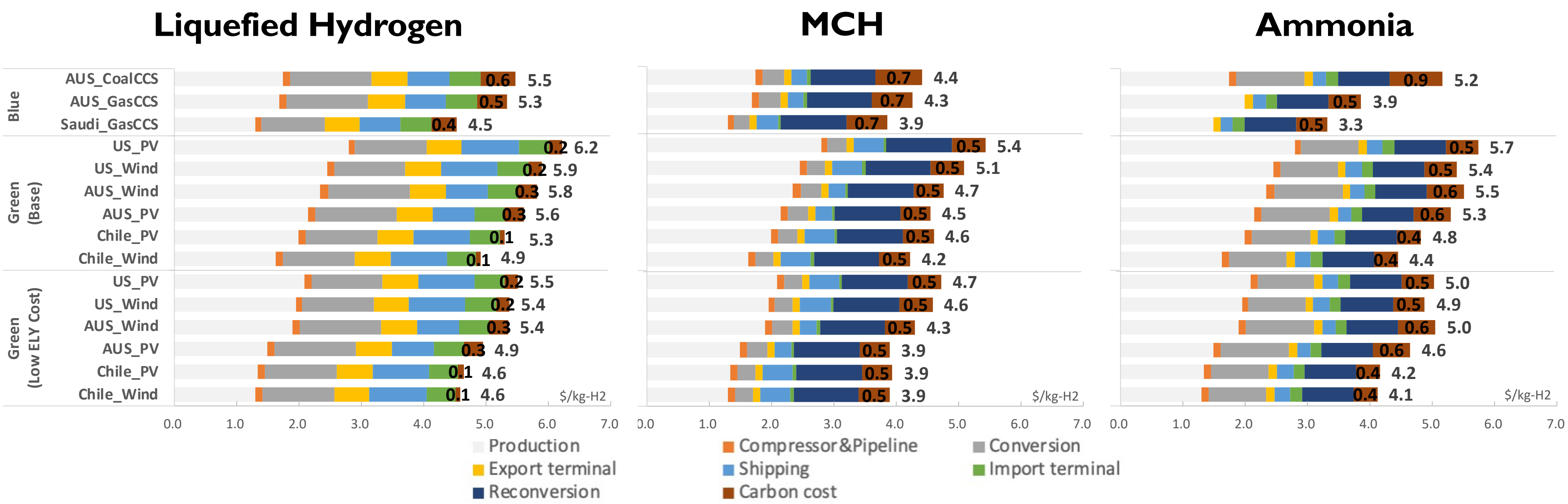
- ❖ Green hydrogen from Chile has the lowest cost when the hydrogen carrier is liquefied hydrogen or MCH.
- ❖ However, when the hydrogen carrier is ammonia, blue hydrogen (produced with natural gas + CCS) is the cheapest.

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 CO_2 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.

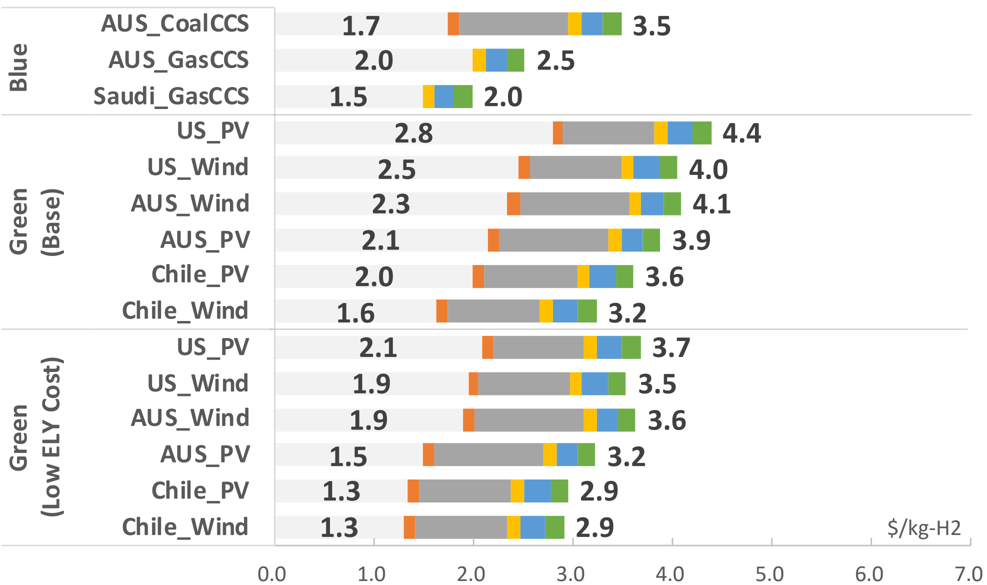
Major Findings: Impact of Carbon Price (assuming 100USD/CO_2 carbon price)



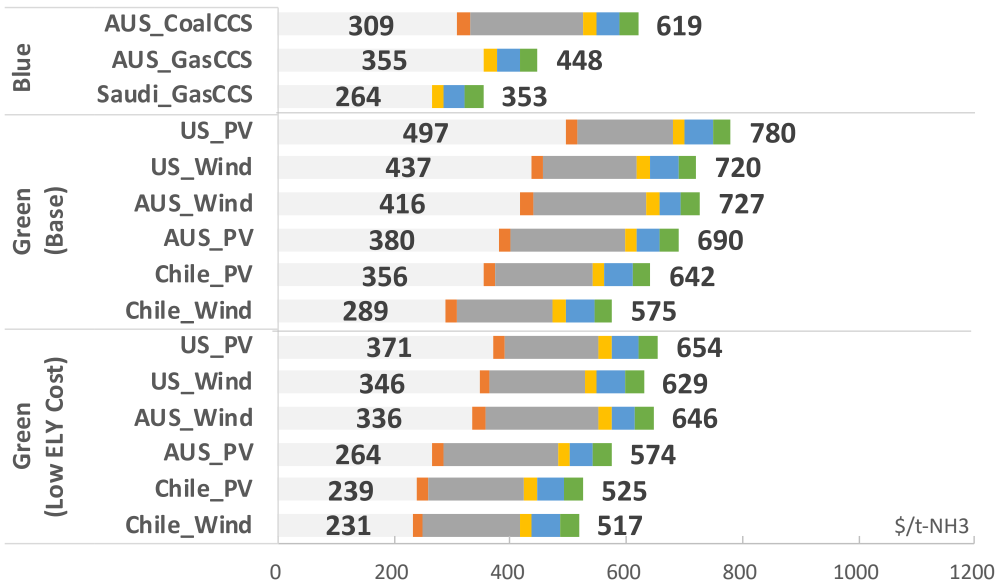
- If hydrogen carrier is liquefied hydrogen or MCH, in the Low Electrolyzer Cost Case the import cost of green hydrogen from Chile can be competitive with blue hydrogen from Saudi Arabia.
- However, when the hydrogen carrier is ammonia, blue hydrogen from Saudi Arabia still has cost advantage.

Major Findings: Ammonia Direct Use

Unit Converted to $/kg-$H_2$



Unit of $/t-$NH_3$

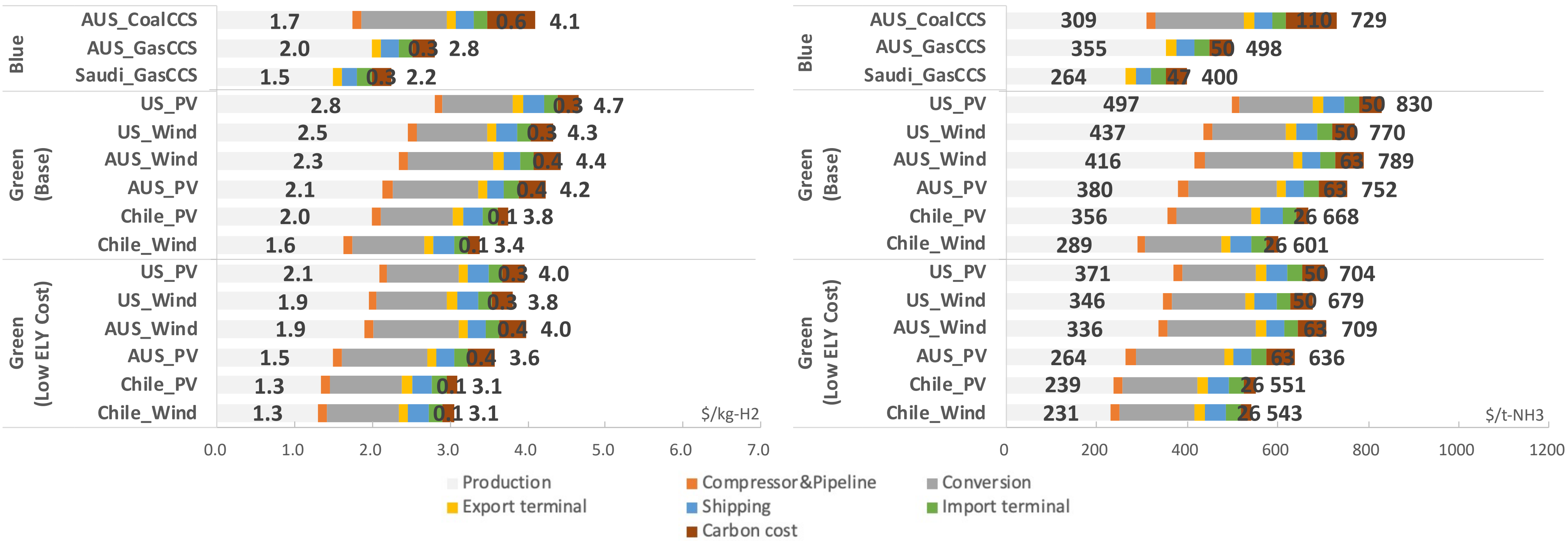


Production Compressor&Pipeline Conversion
Export terminal Shipping Import terminal

❖ 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.

Major Findings: Ammonia Direct Use (carbon price: 100USD/t-CO_2)

Unit Converted to $/kg-$H_2$ | **Unit of $/t-$NH_3$**



❖ Even with a carbon price of 100USD/t-CO_2, the cost advantage of blue ammonia from natural gas (from Australia or Saudi Arabia) can still be maintained.

Outline

(1) Background & Objectives

(2) Methodology & Assumptions

(3) Major Findings

(4) Implications

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/Nm^3(≒3.1USD/kg-H_2) by 2030, 20JPY/Nm^3(≒2.1USD/kg-H_2) 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:
  - ✓ 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
  - ✓ 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

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.

Contact:report@tky.ieej.or.jp