Australian National University

Energy security and low carbon imports

An analysis of the cost-competitiveness of exporting hydrogen from Australia to Europe

Reza Fazeli and Thomas Longden

Produced for the German-Australian HySupply Project

The Australian National University

Canberra ACT 2600 Australia

www.anu.edu.au

CRICOS Provider No. 00120C

Executive Summary

The HySupply project aims to test the viability of a renewable hydrogen supply chain between Australia and Germany. In line with this aim, we assess the cost-competitiveness of exporting green hydrogen and derivative products from Australia to Europe. Four components of the landed cost include levelised cost of green hydrogen production in Australia, cost of conversion (liquefaction, conversion to Ammonia or Methanol), road transport to port and shipping cost.

Main findings from the analysis include: using post-crisis reference prices, landed liquefied hydrogen would cost an addition €22/MWh when imported from Saudi Arabia and €57/MWh from Australia. The cost of shipping liquefied hydrogen is notable, so differences in landed costs between trading partners are a factor to consider. This is a function of distance, due to the need for shipping fuel and boil-off. In contrast, shipping costs of ammonia and methanol are a lower share of the landed cost. Therefore, differences between trading partners is minor. Green ammonia imports are cost-competitive with ammonia prices in the post-crisis period. The landed cost of ammonia from Australia and Saudi Arabia is about €55/MWh lower than the post-crisis reference ammonia price. For methanol, the landed cost from Australia and Saudi Arabia differs by about €10/MWh. There is a mark-up for imported methanol with landed costs €37/MWh and €46/MWh higher than the post-crisis reference price.

The likely suppliers of green liquefied hydrogen are those countries closer to Germany with plentiful renewables that can minimise the costs of shipping and storage. It is more likely that green liquefied hydrogen would come from Morocco, Egypt, and Saudi Arabia due to the lower cost of shipping liquefied hydrogen. The supply of ammonia and methanol could be sourced from a range of countries, as shipping and storage costs are a lower proportion of the overall landed cost. This presents the possibility of Germany having a range of suppliers to ensure energy security and limit the dependence on a few countries. This could include Australia. An important consideration is the need to meet demand for ammonia and methanol, which will place less pressure on the demand for natural gas. It also presents an opportunity to reduce industrial emissions, while the residential sector shifts towards electrification over time. The current cost of gas makes electrification options for residential heating (i.e. heat pumps) more attractive. A key role for Australia is to help supply the green ammonia and green methanol required to decarbonise the existing demand for ammonia and methanol, which currently depends on natural gas.

1 Introduction

Renewable power-to-X (P2X) options are a way for solar and wind resources to be used to decarbonise non-electricity sectors via the production of liquefied hydrogen, ammonia and methanol (Daiyan et al., 2020). These fuels can be shipped and provides an avenue for 'shipping the sunshine' between Australia and Germany (Johnston et al., 2022; Kalt and Tunn, 2022; Wang et al., 2023).

The European Commission's REPowerEU plan, released in May 2022 in response to energy market disruptions from Russia's invasion of Ukraine, aims to rapidly reduce dependence on Russian fossil fuels by 2027. It also increases the 2030 renewable energy target from 40% to 45% (IEA, 2022). In addition, renewable hydrogen was identified as a key energy carrier to replace natural gas, coal and oil in hard-to-decarbonise industries and transport. REPowerEU sets a target of 10 million tonnes of domestic renewable hydrogen production and 10 million tonnes of renewable hydrogen imports by 2030. The German Federal Ministry for Economic Affairs and Climate Action has also launched a procurement procedure for the import of green hydrogen under the H2Global programme. This will support purchase contracts for hydrogen-based ammonia, methanol and sustainable aviation fuel (eSAF) produced outside the EU and EFTA (German Federal Ministry for Economic Affairs and Climate Action, 2022).

Previous studies have tended to focus on some component of the potential supply chain. This study assesses the land cost of liquefied hydrogen, ammonia and methanol in the European Union (EU) from Australia and Saudi Arabia. This comparative assessment highlights the difference that shipping costs make for the viability of P2X options from potential suppliers to key demand regions.

Our analysis shows that the likely suppliers of green liquefied hydrogen are those countries closer to the EU that have plentiful renewables and can minimise the costs of shipping and storage. For Germany, it is more likely that green liquefied hydrogen would come from Morocco, Egypt, and Saudi Arabia due to the notable cost of shipping liquefied hydrogen. However, as shipping and storage costs are a lower proportion of the overall landed cost, the supply of ammonia and methanol could be sourced from a range of countries. This presents the possibility of Germany having a range of suppliers to ensure energy security and limit the dependence on a few countries. This could include Australia.

We also account for higher gas prices by comparing them with cost-competitive reference prices before and after the invasion of Ukraine. These reference prices indicate whether producing green hydrogen in Australia and exporting it to Germany would be cost-competitive, or whether a mark-up would need to be incurred. Theses reference prices are indicative benchmark prices that could be used in a cost for difference contract arrangement. Note that we do not make an assessment of seasonal variations, and the impact on prices and storage. Nor, do we discuss final demand uses of these energy carriers.

2 Methods and data inputs

We started with the analysis of cost-competitiveness of hydrogen and derivatives.

Landed cost estimation includes four components: levelised cost of green hydrogen production in Australia, cost of conversion (liquefaction, conversion to Ammonia or Methanol), road transport to port and shipping cost, as described below:

Landed Cost = $Cost_{H2\ Production} + Cost_{Conversion} + Cost_{road\ transport} + Cost_{Shipping}$

Levelised cost of hydrogen production is estimated from the present value of all expenses during the plant's lifetime and the present value of hydrogen generation, as:

$$Levelised\ Cost_{H2\ production} = \frac{\sum_{t=0}^{N} \frac{C_t + O_t + F_t}{(1+r)^t}}{\sum_{t=0}^{N} \frac{H_t}{(1+r)^t}}$$

where C_t represents the capital cost of electrolyser in year t, O_t the annual fixed operation expenditure (OPEX), F_t the annual feedstock cost (electricity), H_t the annual hydrogen production (kg H_2), r the real discount rate, and N the plant lifetime.

Various sources can be considered to supply the required renewable electricity, but we focused on on-site solar PV, because it is projected to provide the lowest cost of renewable power generation in the long run according to latest projections in the GenCost 2022-23 (Graham et al., 2023).

2.1 Cost assumptions

The cost assumptions for green hydrogen produced in Australia are shown in Table 1. We used baseline assumptions for the capital cost of electrolysers, the cost of electricity from renewables, and the cost of transporting the hydrogen to a port. We do not account for seasonality or specific locations, but assume that the hydrogen is produced at a high potential location on the west coast of Australia (Mojiri et al., 2022).

Table 1: Cost assumptions for green hydrogen produced in Australia

	Baseline	Low Capital Cost	Low Feedstock	Source
Capital Cost (Euro/kW)	692	205	692	IEA (2021)
Cost of Electricity (Euro/MWh)	38	38	20	Graham et al., (2023)
Transport to port (Euro/MWh H2)	1.9	1.9	1.9	Bruce S, et al. (2018)

Table 2 shows the mark-ups applied for conversion to liquefied hydrogen, ammonia, or methanol, and the shipping cost, which differs based on distance. Pilbara in Australia to Rotterdam in the Netherlands and Jeddah (Saudi Arabia) to Rotterdam are the key examples used in this analysis. As expected, the cost of shipping is 50-60% lower for LH2, Ammonia and Methanol from Saudi Arabia to Rotterdam compared to the route from Western Australia.

Table 2: Cost assumptions for conversion and shipping

Liquefaction and shipping to Rotterdam			
	Australia to Rotterdam	Saudi Arabia to Rotterdam	**Source**
Liquefaction (Euro/MWh H2)	39.2	39.2	(Bruce et al., 2018)
Shipping (Euro/MWh H2)	59.1	24.6	(Johnston et al., 2022)
Convert to Ammonia and shipping to Rotterdam			
	Australia to Rotterdam	Saudi Arabia to Rotterdam	**Source**
Conversion to Ammonia (Euro/MWh H2)	31.0	31.0	(Bruce et al., 2018)
Shipping (Euro/MWh H2)	15.8	7.6	(Johnston et al., 2022)
Convert to Methanol and shipping to Rotterdam			
	Australia to Rotterdam	Saudi Arabia to Rotterdam	**Source**
Conversion to Methanol (Euro/MWh H2)	28.3	28.3	(Advisian, 2021)
Shipping (Euro/MWh H2)	19.2	9.3	(Johnston et al., 2022)

2.2 Comparison prices before and after the invasion of Ukraine

The reference prices used in the analysis are summarised here (Table 3). The invasion of Ukraine has led to notably higher gas prices (Figure 1) that has impacted the costs of producing ammonia and methanol. The increase in ammonia is notable due to manufacturers reducing production and this has severely limited the supply of ammonia. While wholesale natural gas prices have been above €300/MWh, we used the average for the post-crisis period as a reference cost that may continue to be seen in coming years. There is uncertainty on future prices, so we use these reference prices as being indicative benchmarks for cost-for-difference calculations for the future of fuel supply.

Table 3: Cost assumptions for green hydrogen, conversion and shipping

	Liquefied hydrogen	Ammonia	Methanol
Pre-invasion reference price	€ 66/MWh	€ 56/MWh	€ 62/MWh
Post-invasion reference price	€ 134/MWh	€ 185/MWh	€ 93/MWh
Source	DutchTTF Gas Futures ICE	Clean Energy News	Methanex European Posted Contract Price

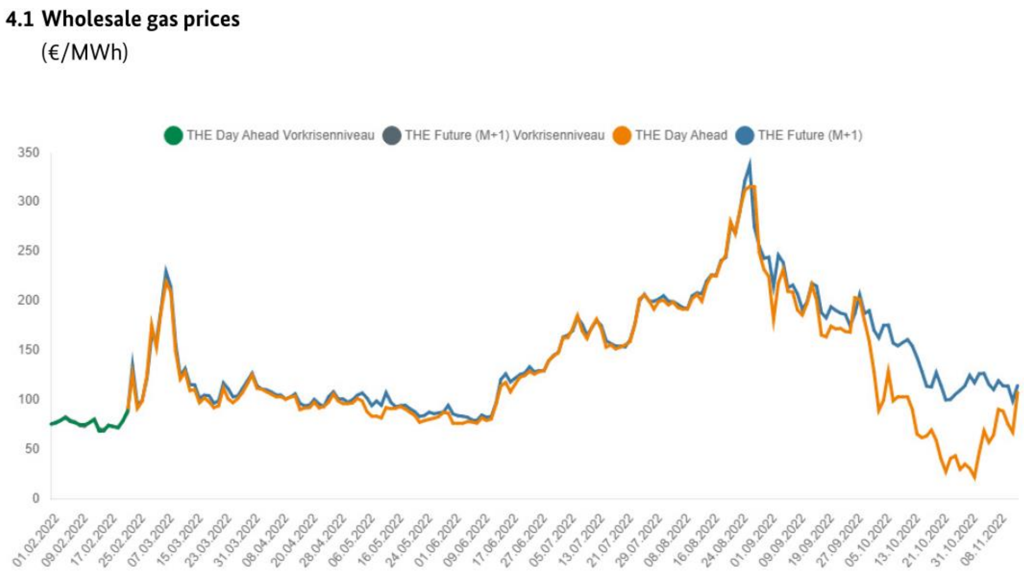

Figure 1: Wholesale natural gas prices (€/MWh) - Trading Hub Europe (THE) – Source (bundesnetzagentur, 2023)

3 Landed cost of energy carriers in Rotterdam

We combined a range of estimates to assess the near-term landed cost of liquefied hydrogen and derivatives, specifically ammonia and methanol, to compare them with reference prices before and after the invasion of Ukraine. These reference prices indicate whether producing green hydrogen in Australia and exporting it to Germany is cost-competitive, or whether a mark-up would be incurred. The reference prices are indicative benchmark prices that could be used in a cost for difference contract arrangement. We do not make an assessment of seasonal variations or final demand uses of these energy carriers. We start with the results of the assessment and then provide information on the numbers used to formulate the landed costs.

3.1 Liquefied hydrogen

The landed cost of liquefied hydrogen imported from Australia would cost about €190/MWh (Figure 2). This compares to about €160/MWh for hydrogen imported from Saudi Arabia. Transport costs increase notably with greater distances, so the selection of trading routes influences the landed cost estimate.

Reference prices are set using the ICE Dutch TTF Natural Gas Futures prices (ICE, 2023). We have selected €66/MWh for the period before the invasion of Ukraine and €134/MWh in the recent period. Prices have fluctuated but these prices are useful as benchmarks.

The landed cost of liquefied hydrogen from Australia is almost €60/MWh higher than the post-crisis reference price (€134/MWh). The cost difference narrows with lower electrolyser capital costs (low CAPEX in Figure 2) and lower costs of renewables (low feedstock). The landed cost of liquefied hydrogen from Saudi Arabia is just above €20/MWh higher than the post-crisis reference price.

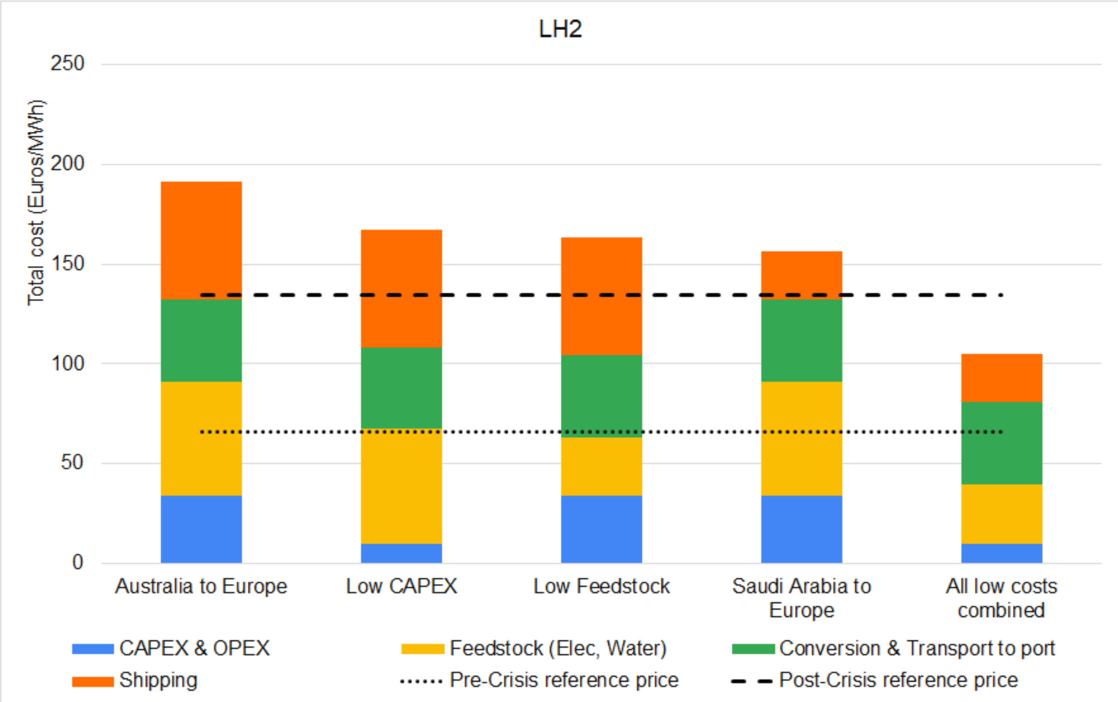

Figure 2: Landed cost of liquefied hydrogen (LH2)

3.2 Ammonia

The landed cost of ammonia imported from Australia would cost about €140/MWh (Figure 3). This compares to about €130/MWh for hydrogen imported from Saudi Arabia. Lower shipping costs means that the difference between supply countries is smaller than for liquefied hydrogen. Therefore, for importer countries, the choice of trading partner has a smaller premium.

Reference prices for ammonia are set using recent prices mentioned in news articles (Moser, 2022) as well as academic literature (Fasihi et al., 2021). We have selected €56/MWh for the period before the invasion of Ukraine and €185/MWh in the recent period. Higher gas prices and lower production has led to notable increases in the cost of ammonia.

The landed cost of ammonia from Australia and Saudi Arabia is about €55/MWh lower than the post-crisis reference price. Lower electrolyser capital costs (low CAPEX in Figure 3) and lower costs of renewables (low feedstock) could lead to landed costs around €110/MWh.

If both lower electrolyser capital costs (low CAPEX) and lower costs of renewables (low feedstock) occur simultaneously then landed green ammonia costs move towards the pre-crisis reference price.

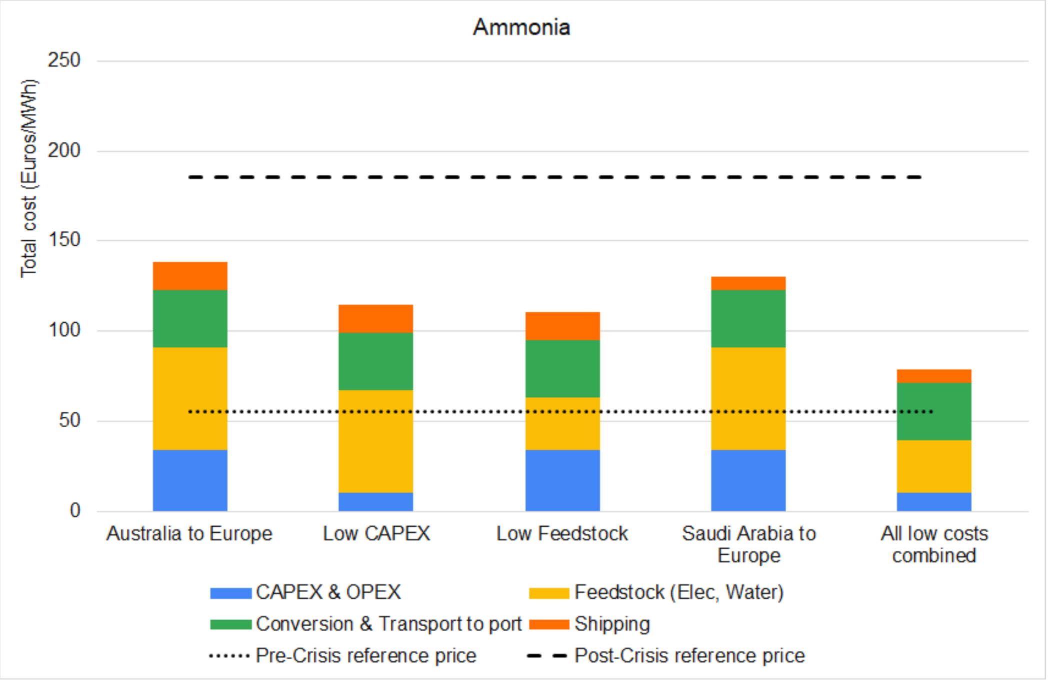

Figure 3: Landed cost of ammonia

3.3 Methanol

The landed cost of methanol imported from Australia would also cost about €140/MWh (Figure 4), which is similar to the ammonia cost. This compares to about €130/MWh for hydrogen imported from Saudi Arabia. Lower shipping costs, compared to liquefied hydrogen, means that the difference between the two countries is about €10/MWh. Again, the difference in costs between supply countries is smaller than for liquefied hydrogen. Hence, the choice of trading partner could be less influential.

Reference prices for methanol are set using the Methanex European Posted Contract Price (Methanex, 2023). For the period before the invasion of Ukraine, the reference price is €62/MWh and €93/MWh for the recent period.

The landed cost of methanol from Australia and Saudi Arabia is €37/MWh and €47/MWh higher than the post-crisis reference price. Lower electrolyser capital costs (low CAPEX in Figure 4) and lower costs of renewables (low feedstock) could lead to landed costs around €112/MWh.

If both lower electrolyser capital costs (low CAPEX) and lower costs of renewables (low feedstock) occur simultaneously then landed green methanol costs fall in the middle of pre-crisis and post-crisis reference price.

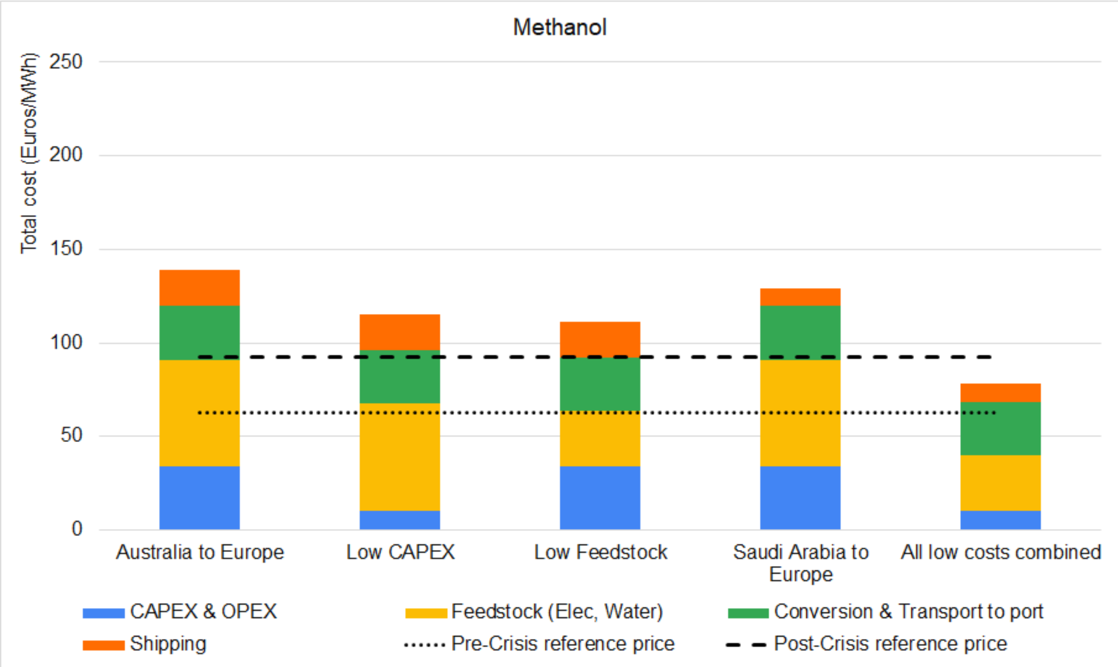

Figure 4: Landed cost of methanol

We reviewed the costs of producing and shipping liquefied hydrogen, ammonia, and methanol and compare these costs to reference prices, which could be the basis of cost for difference contracts (Figure 5).

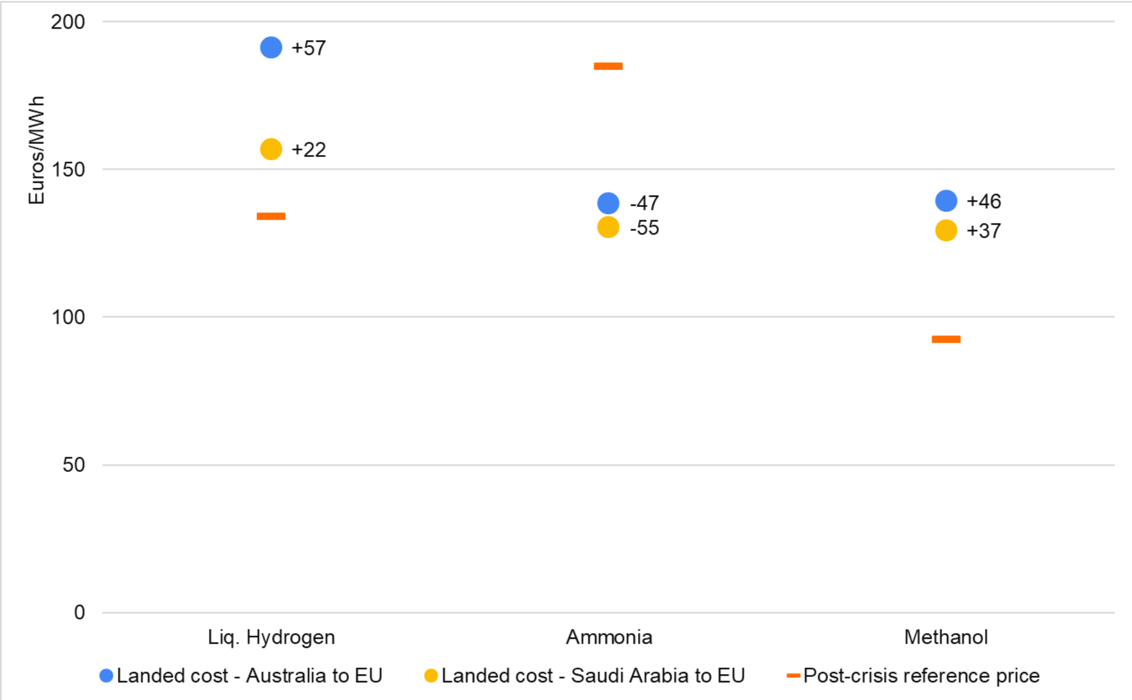

Figure 5: Landed cost of liquefied hydrogen, ammonia and methanol

4 Conclusion

We evaluate the cost-competitiveness of exporting green hydrogen and its derived products from Australia to Europe. We conclude that while there is a market for hydrogen derivatives, there is a big cost disadvantage for liquefied h2.

When using post-crisis reference prices as a basis, the addition to the cost of landed liquefied hydrogen would be approximately €22/MWh when sourced from Saudi Arabia and around €57/MWh if imported from Australia. Conversely, the landed cost of ammonia originating from Australia and Saudi Arabia is approximately €55/MWh lower than the post-crisis reference ammonia price. In the context of methanol, the landed cost from Australia and Saudi Arabia differs by about €10/MWh, with a noticeable markup for imported methanol. The landed costs for methanol are approximately €37/MWh and €46/MWh higher than the post-crisis reference price, from Saudi Arabia and Australia, respectively.

Our analysis also indicates that countries in closer proximity to the EU with abundant renewable resources, capable of reducing shipping and storage expenses, are the probable sources of green liquefied hydrogen. In the case of Germany, it's more likely that green liquefied hydrogen would be sourced from countries like Morocco, Egypt, and Saudi Arabia, primarily due to the significant costs associated with shipping liquefied hydrogen.

Contribution attribution

Reza Fazeli; Conceptualization, Formal Analysis, Data collection, Writing- Review & Editing

Thomas Longden; Conceptualization, Data collection, Writing- Original draft preparation

Acknowledgements

The authors acknowledge funding from the Australian Government's Department of Foreign Affairs and Trade supporting Australian participation in HySupply project.

References

Advisian, 2021. Australian hydrogen market study - Sector analysis summary.

Bruce, S., Temminghoff, M., Hayward, J., Schmidt, E., Munnings, C., Palfreyman, D., Hartley, P., 2018. National Hydrogen Roadmap.

bundesnetzagentur, 2023. Gas Price [WWW Document].

Daiyan, R., MacGill, I., Amal, R., 2020. Opportunities and Challenges for Renewable Power-to-X. ACS Energy Lett. 5, 3843–3847. https://doi.org/10.1021/acsenergylett.0c02249

Fasihi, M., Weiss, R., Savolainen, J., Breyer, C., 2021. Global potential of green ammonia based on hybrid PV-wind power plants. Appl. Energy 294, 116170. https://doi.org/https://doi.org/10.1016/j.apenergy.2020.116170

German Federal Ministry for Economic Affairs and Climate Action, 2022. Federal Ministry for Economic Affairs and Climate Action launches first auction procedure for H2Global – €900 million for the purchase of green hydrogen derivatives [WWW Document]. bmwk. URL https://www.bmwk.de/Redaktion/EN/Pressemitteilungen/2022/12/20221208-federal-ministry-for-economic-affairs-and-climate-action-launches-first-auction-procedure-for-h2global.html

Graham, P., Hayward, J., Foster, J., Havas, L., 2023. GenCost 2022-23.

ICE, 2023. Dutch TTF Natural Gas Futures [WWW Document]. URL https://www.ice.com/products/27996665/Dutch-TTF-Gas-Futures/data?marketId=5640640&span=3

IEA, 2022. Is the European Union on track to meet its REPowerEU goals? Paris, France.

Johnston, C., Ali Khan, M.H., Amal, R., Daiyan, R., MacGill, I., 2022. Shipping the sunshine: An open-source model for costing renewable hydrogen transport from Australia. Int. J. Hydrogen Energy 47, 20362–20377. https://doi.org/10.1016/j.ijhydene.2022.04.156

Kalt, T., Tunn, J., 2022. Shipping the sunshine? A critical research agenda on the global hydrogen transition. GAIA - Ecol. Perspect. Sci. Soc. 31, 72–76.

Methanex, 2023. Methanol price [WWW Document]. URL https://www.methanex.com/about-methanol/pricing/ (accessed 10.20.23).

Mojiri, A., Coventry, J., Beck, F., Fazeli, R., Hosseini, T., Pye, J., Rahbari, A., Wang, Y., 2022. HILT CRC Green Hydrogen Supply Modelling for Industry.

Moser, J., 2022. Why green ammonia will be the workhorse of EU's future hydrogen economy [WWW Document]. URL https://www.euractiv.com/section/energy/opinion/why-green-ammonia-will-be-the-workhorse-of-eus-future-hydrogen-economy/ (accessed 10.20.23).

Wang, F., Swinbourn, R., Li, C., 2023. Shipping Australian sunshine: Liquid renewable green fuel export. Int. J. Hydrogen Energy 48, 14763–14784. https://doi.org/https://doi.org/10.1016/j.ijhydene.2022.12.326