INSIGHT BRIEFING SERIES

Hydrogen as a cargo

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The Getting to Zero Coalition is committed to accelerating shipping decarbonization by getting commercially viable deep sea zero emission vessels powered by zero emission fuels into operation by 2030 to put shipping on a path for full decarbonization by 2050. To unpack the different fuels and technologies options that could support the transition to zero emission fuels, the workstream on Fuels & Technologies has hosted a series of webinars, gathering perspectives from experts across the maritime value chain - shipowners, operators, charterers, financial institutions, classification societies, and NGOs. The insight briefing paper series aims to reach a broader audience and build a common understanding of the fuels, engines, and storage technologies that will enable the decarbonization transition.

The Insight Brief is based on analysis by Global Maritime Forum for the Getting to Zero Coalition, a partnership between the Global Maritime Forum and the World Economic Forum, made possible with funding from Mission Possible Partnership.

Date of the webinar: May 2021

Watch the webinar here.

Panelists:

- Ita Kettleborough, Deputy Director, Energy Transitions Commission
- Shigeru Muraki, Representative Director, Clean Fuel Ammonia Association
- Brett Cooper, Chairman, Renewable Hydrogen Pty Ltd
- Nikunj Gupta, General Manager hydrogen import export, Shell

Moderator: Randall Krantz, Senior Project Advisor on Shipping Decarbonization, Global Maritime Forum/Getting to Zero Coalition

Executive Summary

Synopsis: The use of zero emission fuels in shipping will be built, in part, on the back of new global hydrogen supply chains. While some hydrogen will be locally used or transferred in pipelines, global trade in hydrogen by ship is expected to grow. Hydrogen will be shipped in the form of compressed or liquid hydrogen, and more likely ammonia or maybe methanol which have much higher energy densities. All three options present opportunities for this cargo to be used as a shipping fuel. For this to happen, the right infrastructure would need to be in place. In both heavy industry and mobility, the technologies needed to achieve net-zero emissions exist and are either already commercially available today or nearing technological maturity.

Key takeaways:

> Colours create uncertainties. In order to trigger investments, globally, by mid-century around 500-800 million tons of zero-emission hydrogen is needed for a decarbonised global economy (covering all end-uses)

> While hydrogen's low energy density makes it difficult to use as a fuel for deep sea shipping, it can be part of a flexible pathway to fully decarbonize the maritime industry as it is a feedstock for zero-emission ammonia and methanol, potential candidates to enable the transition to zero by mid-century.

> Exactly how hydrogen will move around the world is uncertain. Supply chain costs will vary depending on the form in which hydrogen will be transported (hydrogen or a vector like

ammonia), and the mode e.g. by pipeline, truck or ship. The optimal hydrogen transport mode will vary by distance, terrain and end-use: no universal solution exists.[1]

> The timeline for deployment of hydrogen as a cargo will be highly influenced by early learning from pilots and demonstrations. Training and standards will be important for safe deployment.

Detailed Summary

About hydrogen

As the shipping industry explores what the zero carbon fuels of the future will be, there is broad acknowledgement that hydrogen-based fuels with zero or low carbon will play a critical role in the medium and long term. According to the Hydrogen Council, there are three different types of hydrogen depending on the production process. Each types depend on the feedstock and therefore the amount of CO2 released during the production process:

- "Green" hydrogen is produced from renewable electricity and water through electrolysis
- "Blue" hydrogen is produced from natural gas using steam methane reformation (SMR) combined with carbon capture and storage (CSS)
- "Grey" and "black" hydrogen are produced from fossil fuels through the process of gasification or steam methane reformation (SMR)[2]

95% of the world's hydrogen currently comes from fossil fuels, while in the near to medium-term, the cheapest zero emission hydrogen comes from electrolysis of water using renewable electricity (wind and solar power).

Opportunities and challenges with hydrogen as a cargo and fuel source according to the webinar

Below, the opportunities and challenges in regards fuelling vessels on hydrogen while carrying the fuel as a cargo.

Opportunities:

- Flexible: Hydrogen can be blended into the natural gas and ammonia grid at many locations, allowing production to be sited alongside other hydrogen off-takers. Off-take can be varied, with no requirement for steady-supply.
- Scalable: There is a need to drive down the cost of renewable electricity that can enable the energy transition, which will among other things, drive down the cost of green hydrogen. In the case of green hydrogen there is no limitation in feedstock availability.

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1 Hydrogen Council and McKinsey Company (2021). A perspective on hydrogen investment, market development and cost competitiveness.

2 Hydrogen Council (2021). Hydrogen decarbonization pathways.

Challenges:

- Complex overall pricing method can have a high variation due to production cost, port system location and form of transportation
- Level of cooperation: the deployment of green hydrogen will depend on the capacity to develop training and standards to address safety issues

1. The hydrogen economy

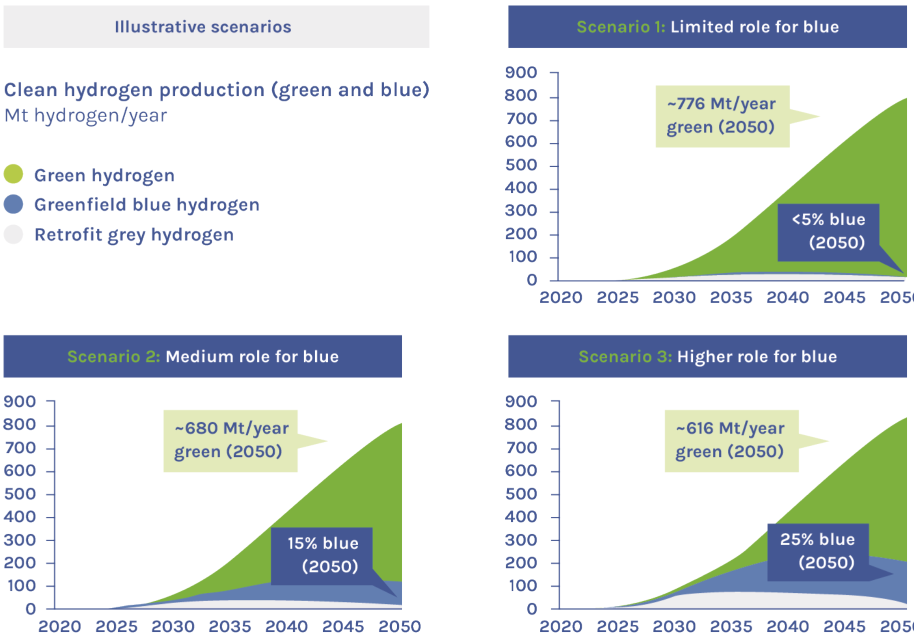
According to a recent report by the Energy Transitions Commission, in the fundamental transition of the energy system, total global need for zero-emission hydrogen for mid-century is around 500 to 800 million tons per annum, a five to seven-fold increase from today's outputs. As a matter of fact, zero-emission hydrogen and ammonia will represent 15%-20% of the final energy demand in a net zero economy in 2050.[3]

According to Ita Kettleborough, Deputy Director, Energy Transitions Commission, green hydrogen will be the major route for decarbonization in the long term enabled by an expected drop in renewable energy prices along with decreasing CAPEX for electrolysers. In parallel, blue hydrogen will play a role in this transition with advances in carbon capture and storage (CCS) and validated assessments of low leakage rates. Depending on the scenarios, blue hydrogen could represent between five and twenty-five percent of hydrogen production by 2050.

3 Energy Transition Commission (2021). Making the Hydrogen Economy Possible: Accelerating Clean Hydrogen in an Electrified Economy.

Exhibit 1: *Ramp up of green and blue hydrogen*

Source: *Energy Transition Commission (2021)*



As the demand for hydrogen grows across all industries, transport will play a major role in connecting production, storage, and end use. Hydrogen can be transported in the form of a gas, liquid or a more energy-dense carrier such as ammonia or methanol. It can be carried by trucks in small volumes, via pipelines, or on vessels over long distances. The overall price is also determined by local availability for renewable electricity and the cost of electrolysers.

Shigeru Muraki the Representative Director of the Clean Fuel Ammonia Association (CFAA) provided some orders of magnitude: for example, if ammonia comprises 10% of existing marine fuel, the total demand will be 100 million tons of ammonia, half of the actual volume currently produced for fertilizer.

2. The cost of hydrogen and the regional incidence

There are different costs of hydrogen: operational cost and lifecycle cost. The most commonly quoted figure for fossil hydrogen pricing is derived from steam methane reforming (SMR) technologies, which can produce hydrogen from natural gas at around USD 1-1.50/kg of hydrogen.[4] This is widely seen as the target for renewable hydrogen to be competitive. By 2030, assuming scaled production and adequately developed transportation infrastructure, hydrogen could be shipped from locations such as Australia, Chile or the Middle East to projected demand centres at costs of USD 2-3/kg of hydrogen,[5] with lower costs at point of production.

Shigeru Muraki explained that a scale up of the market can drive down costs. For increased competitiveness, liquid hydrogen needs to be scaled 100 times with pilots and demonstrations to boost commercial use. It is the same pathway as liquid gas.

During the webinar, Ita Kettleborough noted that the cost of production and transport will influence the cost of hydrogen. The cost of production is driven by the cost of feedstock and therefore, the cost of renewable energy. The cost of transport will depend on the transport itself whether by truck, pipeline, or ship. Shipping is cost-competitive only for long distances and requires conversion of hydrogen, into liquid hydrogen, ammonia, or possibly methanol. If there is a need for reconversion back into hydrogen, for example for use in steel smelting, the total hydrogen cost depends on the reconversion, which will have a strong impact on the final cost. Each conversion and reconversion incurs efficiency losses and adds to the final cost of the hydrogen.

The geography will play a major role in the final cost depending on the scalability of renewable electricity technologies. Early and cost-effective development of the hydrogen economy may best occur within clusters which de-risk investment and support the simultaneous and mutually-reinforcing development of hydrogen production and end use. The Energy Transition Commission demonstrated that wind and solar levelized costs of electricity (LCOEs) have dramatically decreased in the last 10 years with the latest lowest auction prices for solar photovoltaic below $20/MWh [Exhibit 2]. In addition, the LCOEs vary by geography from $26/MWh in India, $36/ MWh in China, $42/MWh in the United States, to $114/

4 World Bank & ESMAP (2020).Green Hydrogen in Developing Countries.

5 Hydrogen Council and McKinsey Company (2021). A perspective on hydrogen investment, market development and cost competitiveness.

MWh in Japan [Exhibit 3].[6]

6 Energy Transition Commission (2021). Making Clean Electrification Possible: 30 years to electrify the global economy.

Exhibit 2: *Photovoltaic and wind LCOE global benchmark*

Source: *Energy Transition Commission (2021)*

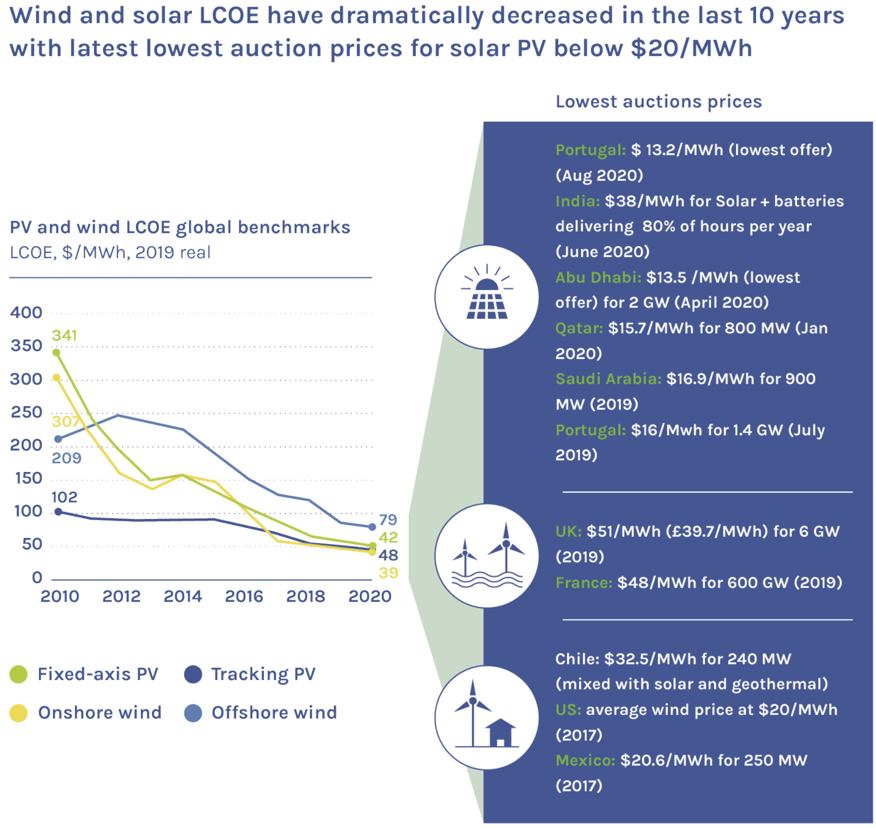
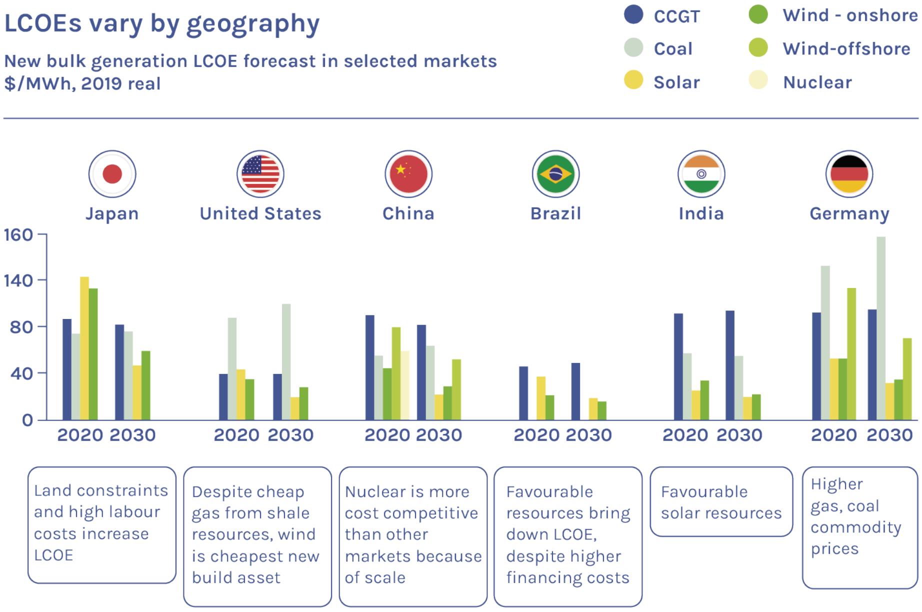


Exhibit 3: *New bulk generation LCOE forecast in selected markets*

Source: *Energy Transition Commission (2021)*



Ita Kettleborough concluded that this will create a new geographic division and perspective putting the spotlight on countries with high renewable energy potential. An example is the partnership between the Partnering for Green Growth (P4G) and the Getting to Zero Coalition developing a project that aims to leverage the P4G platform to engage stakeholders and companies from Indonesia, Mexico and South Africa, and together identify concrete, actionable business opportunities in the transition to zero emissions shipping, that can contribute to sustainable and inclusive economic growth in the P4G partner countries.

3. Scaling hydrogen as a cargo

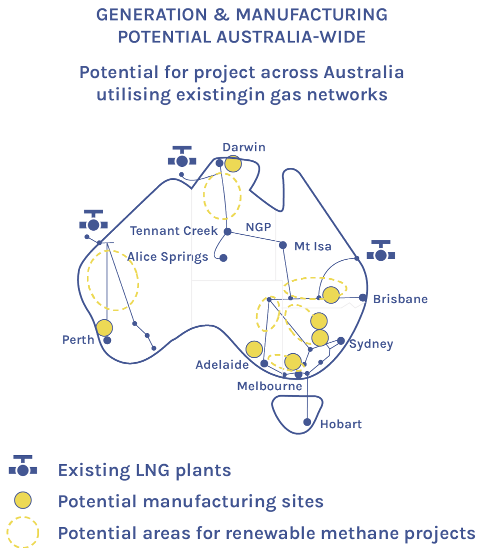
a. *Demonstration and pilots projects*

During the webinar, Southern Green Gas and Shell presented demonstration projects for hydrogen as a cargo.

Brett Cooper, Chairman, Renewable Hydrogen Pty Ltd, presented an Australian case study in which Southern Green Gas uses solar resources to produce green methane, which is sent into existing pipelines to be delivered to LNG facilities on the coasts, as per shown on the network of methane transmission pipelines in Australia [Exhibit 4]. In this case, the use of methane in the pipeline rather than hydrogen is due to the age and quality of the pipeline which would not be suitable for pure hydrogen.

Exhibit 4: *Methane pipeline network in Australia 2021*

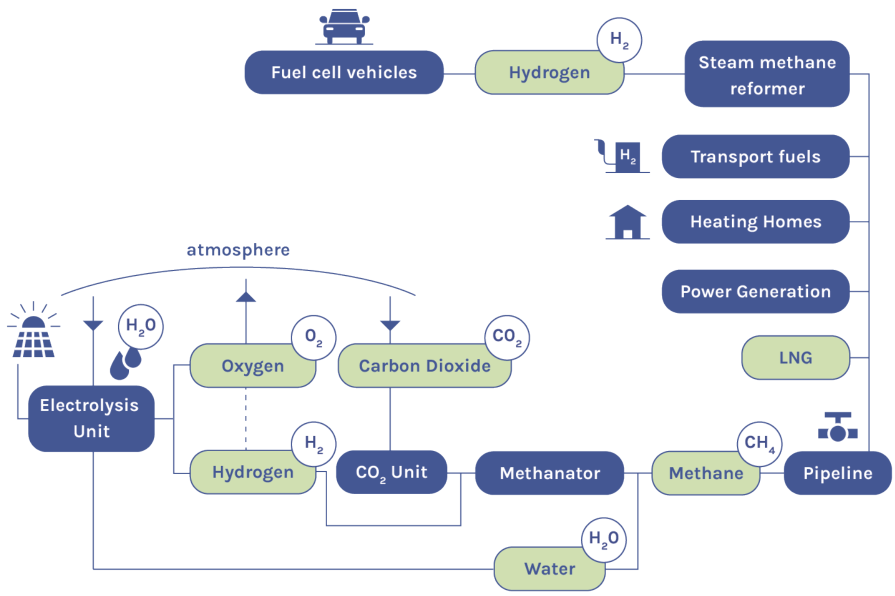
Source: *Southern Green Gas adapted from Sydney University (2021)*



Electricity is produced by modular solar panels in the non-arable land close to methane and natural gas pipelines. The key of this technology is the direct air capture (DAC) units powered by solar energy to synthesise e-methane from CO2 and green hydrogen from electrolysis. This same methane then flows into the network of transmission pipelines which gives the opportunity for new plant production to expand around [exhibit 5].

Exhibit 5: *Direct air capture powered by solar energy*

Source: *Southern Green Gas adapted from Sydney University (2021)*

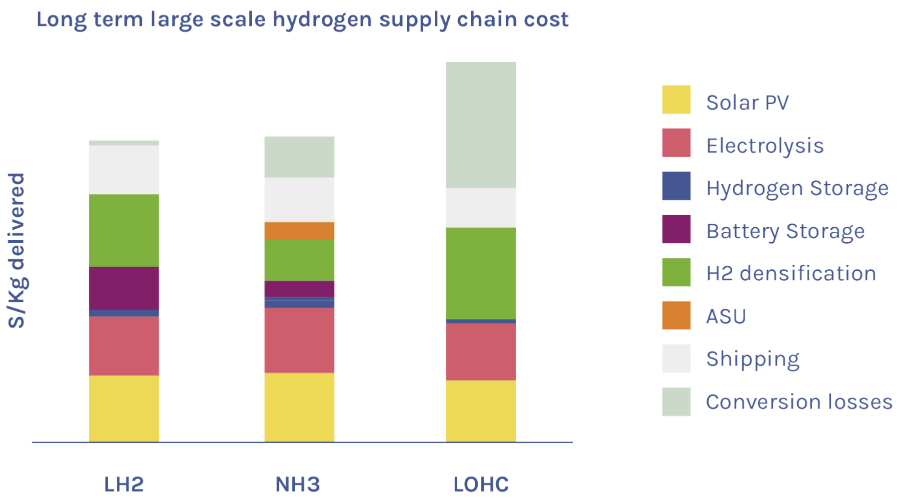


> The unique opportunity in Australia is to produce this green methane in what we call 'one cent land'. These are areas of Australia where the solar intensity is so high, the land cost so low and at vast scale that we can produce electrons at $10 per MW hour, hence one cent per kW hour. In this case, 50 kilowatts per hour produces 1kg of hydrogen at an energy cost of $50 cents considering the one cent land.
>
> Brett Cooper

The second example was presented by Nikunj Gupta, General Manager Hydrogen Import Export at Shell. Gupta described an unbalanced global energy production and highlighted the need to transport energy from renewable country producers to other countries that might face energy shortage and want to meet their carbon commitments. Taking into account the whole supply chain, for Shell, liquid hydrogen along with ammonia, is one of the most competitive energy to move at scale [exhibit 6].

***Exhibit 6:** Carbon free energy carrier options*

***Source:** Shell (2021)*



The company is prioritising the development of liquid hydrogen because it is one of the leading options in the market and also because there is a need for supply chain development. In this context, the world's first liquefied hydrogen carrier, the **Suiso Frontier** was born from a collaboration between Shell, Kawasaki, Itawani Corporation and Electric Power Development Co. This project is the first step to commercialise a liquid hydrogen supply chain by 2030.

b. Standards and training

In order to scale the use of hydrogen, according to Kettleborough, standards and traceability mechanisms are needed to label and certify the production of zero-emission hydrogen and transport. It will be necessary to track the carbon intensity of electricity during the hydrogen generation, which will depend on the proportion of renewable electricity used for green hydrogen, or the carbon capture rates and methane leakage through the supply chain for blue hydrogen.

As often noted, in order for hydrogen to be transported in the form of ammonia, there is a need to ensure that it is safe for seafarers. According to Gupta, in order to ensure safety, standards are needed ahead of the execution of a project and broader deployment. In Tasmania, the Australian Maritime College currently offers an online and in person safety program for seafarers. The program was developed in partnership with the Ammonia Safety Training Institute, and Cooper highlighted that knowledge can be transferred from one energy source or industry (e.g. fertilizer) to shipping.

c. A role for Getting to Zero Coalition to support the industry for scale

According to the panellists, there is a need to develop networks between stakeholders and to bring organisations and states together to move forward. In addition, the highlight of pilot projects and creation of match making opportunities between off-takers could support the scale of hydrogen. Finally, showcasing different options already existing and operating in the market remain a lever to enable the transition. Indeed, it is a support to benefit from those experiences, to develop a timeframe for scale and to keep the discussion ongoing.

Conclusion

Zero-emission hydrogen demand is expected to increase at least 500% by mid-century. Green hydrogen is highly influenced by the price of renewable electricity, and the cheapest green hydrogen will be produced in regions with the cheapest renewables, which will require transport to regions with highest demand. While the density of pure hydrogen does not make it a strong candidate for large-scale export, demand will drive some exports in the form of ammonia or e-methane. This will pave the way for infrastructure for these commodities, and their future use as a shipping fuel.