MARITIME INDUSTRY

Is hydrogen the key enabler for low-carbon shipping?

In late 2019, Kawasaki Heavy Industries introduced the first liquefied hydrogen carrier

Photo: Kawasaki Heavy Industries

There are compelling reasons to believe that hydrogen could unlock a low-carbon future for the maritime sector. But significant logistical questions remain to be answered, writes *Sotirios Mamalis* of the American Bureau of Shipping.

Reliable, clean, and affordable alternative fuels will be the main enablers of the decarbonisation of shipping. With the strong correlation between seaborne trade and GDP growth, decoupling transport emissions from GDP is one of the largest challenges facing the maritime industry today.

Significant progress has been made since the International Maritime Organization (IMO) published its long-term greenhouse gas (GHG) reduction strategy with a view of 2030 and 2050 milestones. But, despite the advent of new vessel technology and operational measures, these factors are not enough to accomplish the required reductions in GHG emissions from shipping.

There is a clear need for low and zero-carbon fuels. In addition to the long-term GHG reduction strategy, the IMO has recently introduced two short-term measures, the EEXI and CII, which make the use of low and zero-carbon fuels a critical component of shipping in the near term. So how is a change in marine fuels implemented?

Paradigm shift

Utilising such fuels for propulsion requires a large investment and major changes to a typical ship that has a lifetime of approximately 30 years. If a ship adopts a new technology to reduce its environmental impact, the decision must consider the environmental benefits during the entire operational lifetime of the vessel.

From a shipowner's perspective, the economic reality of using alternative fuels is of paramount importance, because this directly impacts the profitability of a vessel. From a fuel provider's perspective, technical concerns are the priority. For authorities and governments, economic factors are most important, because they dictate the number of subsidies needed for introducing alternative fuels for marine use.

Using a low or zero-carbon fuel will require either a holistic rethink of vessel design at the new building stage, or extensive retrofits of existing vessels. In both cases, the equipment required for fuel containment and storage, fuel supply and power generation systems necessitate considerable investment. Analysing these investments helps shipowners to balance the economic and environmental factors and inform their decisions for their future fleet. An additional economic factor is the price of alternative fuels themselves, which is expected to decrease as the production of such fuels is scaled up.

Transporting hydrogen

Hydrogen and ammonia are the two fuels expected to offer the most benefits to the decarbonisation of shipping, since they have zero carbon content and can be produced using renewable sources.

The potential for hydrogen to offer zero-emission power generation and propulsion has made it very attractive for multiple applications. Countries such as Japan and South Korea have already published their hydrogen economy roadmaps showing their ambitious goals. Japan aims to commercialise hydrogen power generation, along with international hydrogen supply chains, and reduce the unit cost of hydrogen power generation to \$0.16/kWh by 2030.

Meanwhile, South Korea is projected to develop a hydrogen market of over \$24bn by 2030 to deploy 15 GW of utility-scale and 2.1 GW of commercial and residential fuel cells by 2040. The European Union hydrogen strategy estimates up to \$570 bn of investment, with Germany, Spain, and France leading the way.

Similar initiatives are expected to be announced by many other countries and governments in the following years. The wide adoption of hydrogen as a fuel for stationary power generation, automotive, marine and aviation applications will create the opportunity for the marine sector to carry hydrogen as cargo and support the global supply chain from the production to the consumption sites.

However, this opportunity comes with some challenges, primarily associated with the design and construction of Liquefied Hydrogen Carriers (LHC), the development of port site facilities for hydrogen liquefaction and loading, as well as facilities for hydrogen unloading and storage at the destination terminals.

In late 2019, Kawasaki Heavy Industries introduced the first LHC, capable of carrying 1,250 m^3 of hydrogen over a range of nearly 5,000 nautical miles from Australia to Japan. The vessel uses a vacuum-insulated double-shell cargo tank capable of storing hydrogen at -253°C and a diesel-electric propulsion system.

Kawasaki also partnered with the Port of Hastings in Victoria, Australia to develop the required hydrogen liquefaction and loading facilities, and developed the unloading terminal in Kobe, Japan. Due to the low volumetric energy density of hydrogen under standard conditions, the need for efficient storage of this fuel is high.

Hydrogen can be produced from many different sources, utilising conventional or renewable energies, which determine the cost of the fuel to the end user, as well as its lifecycle carbon footprint. Hydrogen can be produced from fossil fuels and biomass, or from water, or from a combination of the two. In terms of energy usage, the present-day energy used globally to produce hydrogen is about 275 Mtoe, which corresponds to 2% of the world energy demand, according to the IEA.

Natural gas is the primary source of hydrogen production – this 'grey' hydrogen accounts for 75% of the global total – and is used widely in the ammonia and methanol industries. The second-largest source of hydrogen production is coal (23%), which is dominant in China. The remaining 2% of global hydrogen production is based on oil and electric power. However, the most interesting future option is the production of green hydrogen through electrolysis of water using fully renewable energy.

The availability and low cost of coal and natural gas makes the production of brown and grey hydrogen more economical in the near-term. The cost of brown and grey hydrogen ranges between $1 and $4 per kg, whereas green hydrogen currently ranges between $6 and $8 per kg. The cost of producing green hydrogen since 2015 has fallen by about 50%, and this trend is expected to continue up to 2030 and beyond, as the projects focused on deploying renewable energy for hydrogen production increase.

Hydrogen hubs using a combination of wind, solar and wave energy to lower the cost of production are expected to appear with the deployment of proven technology. Reducing the cost of green hydrogen to $2 per kg or less can make it competitive for use in the marine sector.

The heating value of hydrogen is the highest among all candidate marine fuels at 120 MJ/kg. However, its energy density per unit of volume, even when liquefied, is significantly lower than that of distillates. Compressed hydrogen at 700 bar has only about 15% of the energy density of diesel, and therefore storing the same amount of energy onboard requires tanks about seven times larger. This means that compressed or liquefied storage of pure hydrogen may be practical only for small ships that have frequent access to bunkering stations.

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Finding the right form

The deep-sea fleet may need a different medium to serve as a hydrogen carrier, such as ammonia or liquid organic hydrogen carriers (LOHCs), to limit significant loss of cargo space. Ammonia has higher energy density than hydrogen, which reduces the need for larger tanks, but its advantages need to be weighted against the energy losses and additional equipment required for conversion to hydrogen before it is used in the engines or fuel cells.

Alternatively, ammonia can be used directly as a liquid fuel in engines, rather than in use as a hydrogen carrier. Reducing the size of the tanks needed for hydrogen storage is an active research area. In addition, hydrogen storage in solid-state materials such as metal and chemical hydrides, is in the very early stages of development. This could enable higher density of hydrogen to be stored at atmospheric pressure.

The International Council on Clean Transportation (ICCT) recently completed a study on green hydrogen bunkering infrastructure for trans-Pacific container shipping that offers zero carbon lifecycle emissions. It investigated the potential to develop liquefied hydrogen storage and bunkering infrastructure at multiple locations from the west coast of the US and Canada and the Aleutian Islands all the way to Japan, South Korea and China. By analysing 2015 operations, they found that the associated ports would need to supply 730,000 tonnes of hydrogen annually to fuel all the container ships trading in this corridor.

This number corresponds to about 1% of the hydrogen used in the industrial sector worldwide in 2019. The ICCT study was based on using 2,500 m^3 cryogenic spherical tanks for onsite hydrogen storage. Based on the bunkering needs of different ports along the Pacific Rim, they estimated the required number of tanks to range from three in East South Korea to 39 in San Pedro Bay – corresponding to less than 1% of the area used in the port in every case.

Such studies prove the technical feasibility of hydrogen as cargo and marine fuel and pave the way to strategic planning of the required infrastructure across the globe. While the cost of bunkering facilities is expected to be higher than that of LNG facilities (primarily because of the higher cryogenic storage requirement of liquid hydrogen and the material required for tanks, pipes, and seals) the main cost components are the storage and bunker vessels. These need to be scaled based on the number of ships serviced.

Onsite availability of hydrogen would be needed for small ports, given the lower flows and high cost of dedicated hydrogen pipelines. However, ship and infrastructure costs are a relatively small fraction of total shipping costs over a typical 15–20-year lifespan, with the fuel cost being the primary factor.

From a technology transition perspective, ammonia is expected to be used sooner than hydrogen, primarily because of its higher volumetric energy density and simpler containment and storage systems, which make the economic proposition of ammonia more attractive. However, the production pathways of hydrogen and ammonia are related, therefore the scale up of production facilities will benefit the economics of both fuels. Also, storing hydrogen or ammonia onboard a vessel enables the use of fuel cells for power generation.

Short-sea vessels can benefit from fuel cell technology and transition to electric propulsion with the addition of batteries, which can enable partial zero-emissions operation. Deep-sea vessels are expected to adopt hydrogen later than short-sea vessels when the fuel storage methods are sufficiently developed to enable effective utilisation of the space onboard.

Developing the hydrogen economy is seen in energy and transport sectors as the potential long-term objective to provide a sustainable and clean future. Ship owners, ports and regulatory institutions like the IMO will have to make strategic choices on which methods of hydrogen storage are used in shipping.

The transition to hydrogen requires its production from clean renewable sources to reduce or eliminate its lifecycle environmental footprint, and the deployment of novel fuel storage methods for effective space utilisation onboard the vessels. Hydrogen is an important part of our clean and secure energy future, and a significant contributor to the reduction of greenhouse gas emissions from the marine sector. ●

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