The fuel for a low-carbon future?

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Shipping is facing an uncertain future. The coronavirus pandemic has delivered a (hopefully temporary) blow to economic growth and global seaborne trade. That said, a long-term transformation of the shipping industry is also underway, with environmental issues driving the change. Global trading patterns may change, but the shipping industry will always be part of international supply chains. To play its role in the green transition, it has embarked on a quest for eco-friendly propulsion and fuels for the future.

Since 2006, the International Maritime Organization (IMO) has designated the Baltic as an Emissions Control Area (ECA), regulating fuels to control the level of sulphur oxides (SO_x) leaving a ship's funnel. A global cap on sulphur in ship fuel came into force last year. The effect of this was to make shipping lines either change to low-sulphur fuels (diesel, low-sulphur residual fuel oil, or liquefied natural gas, LNG) or to fit 'scrubbers' to remove the unwanted particles from exhausts. In the Baltic, ships mainly switched to marine diesel, with a few companies betting big on LNG (and nowadays increasingly more on liquid biogas, locally sourced from renewables as is the case in Finland and Sweden).

But this has proved to be just a start. Climate change has become more and more prominent as a global environmental challenge. Shipping, emitting 2-3% of all greenhouse gases (GHG), is expected to play its part in significant emissions reductions. The IMO has published a strategy to meet the Paris Agreement goals: a 50% reduction in GHG emissions by 2050 compared to 2008.

Towards hydrogen systems

Reaching that target will require shipping to change its fuels once more. Given the lack of progress on carbon capture and sequestration, fossil fuels will have to be abandoned and low-carbon fuels developed. Shipping is fortunate in that there are already several technological options on the table. These include wind (zero fuel cost but limited in power and dependent on the weather) and biofuels (many different sources but competing with food production and requiring strict controls to ensure GHG reductions).

The current favourite is, however, hydrogen, offering a range of possibilities. It can be used for combustion with water as the only byproduct; it can deliver electricity through a fuel cell or can be used to produce synthetic fuels. Suppose 'green' hydrogen is produced using renewable energy. In that case, it is a zero-carbon energy carrier that has many potential applications, e.g., as a reducing agent in blast furnaces or for decarbonising cement production. Fuel cells are considered an alternative to battery vehicles where high power or long-range are required in overland transportation. Therefore, hydrogen technologies for shipping can build on technologies from other applications. At the same time, fuel infrastructure can be developed as part of a broader 'hydrogen economy.'

There is now widespread policy support for the development of hydrogen systems. The European Commission (COM) published its ***Hydrogen Strategy for a Climate Neutral Europe*** in 2020, which sees targeted support for hydrogen as part of the European Green Deal. The COM has also established Hydrogen Europe as an industry and research platform for developing hydrogen systems. The 'Hydrogen 2030: the Blueprint' scenario foresees investments across Europe of up to €62bn in hydrogen systems and infrastructure by 2030. Germany's ***The National Hydrogen Strategy*** from 2020 also foresees investing €310m in hydrogen R&D till this decade's end. The EU and its Member States support these strategies through developmental programmes, like the large-scale **EU Fuel Cells and Hydrogen Joint Undertaking** (FCH JU) for R&D and funding under the Horizon Europe R&D programmes.

If these substantial investments come to pass, they could drive a major expansion of hydrogen technologies over the next decade. The response to these policies and R&D initiatives has generated a new wave of projects, with shipping receiving increasing attention as one of the main application areas.

The megawatt range

Shipping hydrogen technologies are still at the developmental stage. It is necessary to upscale current fuel cell technologies for ship propulsion to the megawatt range. An alternative is to develop marine motors that run on hydrogen.

Another challenge is fuel storage. Atmospheric hydrogen is a very light gas. It can be compressed or liquefied to store energy in sufficient quantities for use

onboard ships. Compression to 700 bar is feasible for smaller marine applications, but it is necessary to liquefy hydrogen to deliver a realistic range of operations for larger applications. When at atmospheric pressure, hydrogen must be cooled to -253°C (only 20 centigrade above absolute zero). It requires specially insulated systems and tanks, but LNG is already transported in large quantities at -162°C, so cryogenic technology is already available. *Suizo Frontier*, the first liquid hydrogen tanker, is already undergoing sea trials between Australia and Japan.

An alternative is to carry ammonia that is liquid at -33°C and has a higher energy density than liquid hydrogen. It can be reformed onboard with a catalytic reactor to produce hydrogen. Both alternatives require special attention to safety. If pure hydrogen leaks, it is highly flammable, while ammonia is poisonous. However, both are widely used as industrial chemicals, so safety procedures for design and operation can be developed from industry standards.

The Norwegian car ferry *Hydra*, to be operated by Norled, is one of the leading ship hydrogen projects, launched in November 2020. She will use two 200 kW fuel cells to deliver up to 50% of the power requirements. Another significant project is the planned installation (by 2024) of 2x2 MW fuel cells on the offshore supply vessel *Viking Energy,* with ammonia for energy storage. The BeHydro joint venture of Company Maritime Belge and Anglo Belgian has developed marine motors that run on hydrogen and diesel fuel. The *Hydrotug* for the Port of Antwerp will also be powered by 2x2 MW dual-fuel diesel/hydrogen motors designed by BeHydro. *Hydrotug* should set sail in 2022. Meanwhile, BeHydro is developing a mono-fuel hydrogen motor.

The critical factor

Those and other follow-on projects are expected to demonstrate the feasibility and safety of hydrogen technology in shipping. However, does it mean that hydrogen is *the* fuel for a low-carbon future? Not necessarily.

Motors for ships that run with methanol and ammonia as fuel are also in development and demonstration. However, if any of these fuels are to deliver the necessary reductions in GHG emissions, they will need to be produced using renewable energy sources. For example, within the EU backed FReSMe project, Stena Line has been using the so-called 'blue methanol' to run its ferry *Stena Germanica*. The methanol used in the trial bunkering was produced from CO_2 recovered from the blast furnace gases from SSAB's steel production in Luleå.

Green hydrogen produced from renewables is used by the current technologies that have reached the large-scale development stage. In this sense, shipping is likely to become a part of a hydrogen energy system in the future. Even ships that use wind propulsion will need auxiliary power, so hybrid energy systems – possibly hydrogen – will be installed.

The critical factor, besides emissions reductions, is, of course, the cost of fuel. Any new technology is expensive compared to the current fossil fuel systems that run while ignoring environmental considerations. So the question is instead: what will the relative costs of the various alternatives be, including their supply infrastructure, if they are adopted on a large scale? It is a question that cannot be directly answered, although the current prices of the different fuels are one crucial component. The other is the capital cost of setting up the systems alongside their maintenance. It is challenging to assess and make future forecasts, as had been the case with LNG. Still, one possibility is to adopt product service systems where the shipyard or engine builder 'rent' the power system to the shipowner/operator to reduce the risk of the system being overtaken by later technologies or regulations. Another possibility is to fit 'for but not with,' providing the space and reserves of stability in the ship to allow for changing fuels during the ship's life.

Low-carbon logistics

For now, shipping will have to try out different possibilities for propulsion, see which systems reduce their costs the quickest and look for synergies with other low-carbon energy systems. Hydrogen will probably play one of the central roles, so shipping should actively explore and develop hydrogen technologies as part of low-carbon logistics. Then, the industry will be well-prepared for the rise in societal demand for low-carbon products, including their supply chains. □

Overall, there has been an abundance of hydrogen, fuel cell, and ammonia announcements breaking the news over the past couple of months. Just to name a few:

Copenhagen Airports, Maersk, DSV Panalpina, DFDS, SAS, and Ørsted have partnered to develop an industrial-scaled hydrogen and e-fuel production facility in the Greater Copenhagen Area.

HySHIP, a consortium of 14 European partners, will work on the design and construction of a ro-ro demonstration vessel that will run on liquid green hydrogen (LH2) as well as on the establishment of an LH2 supply chain and bunkering platform.

The Danish shipping line DFDS and its partners have applied for money from the EU Innovation Fund to build a ro-pax equipped with proton-exchange membrane fuel cells.

Corvus Energy and Toyota have partnered to develop and produce sustainable, large-scale, and modularised Proton Exchange Membrane (PEM) fuel cell systems for the international marine market.

DFDS, Arla, Maersk, Danish Crown, and DLG have partnered within the Power-to-Ammonia project to increase the availability of green ammonia as an alternative fuel.

Future Proof Shipping has partnered with the Holland Shipyards Group to retrofit the container barge *Maas* to a zero-emissions hydrogen propulsion system.

The Danish energy company Ørsted has begun construction works on the setup of the 2 MW-strong H2RES site in Copenhagen; the project will investigate how to combine an electrolyser with the fluctuating power supply from offshore wind, using the company's two 3.6 MW turbines at Avedøre Holme.

The IVL Swedish Environmental Research Institute, Sintef, the University of Iceland, Stena Rederi, and Powercell Sweden have initiated a study on how hydrogen and fuel cells compare to other alternative fuels for sea shipping.

The Bornholm Bunker Hub consortium will investigate the potential of establishing a green maritime fuel bunkering station (ammonia) on the Danish island.

The Polish state-owned oil refiner and petrol retailer Orlen has announced it will create a production & distribution chain (nicknamed Hydrogen Eagle) of low- and zero-emission hydrogen throughout Poland, Czechia and Slovakia (the company already operates pilot hydrogen refuelling points at its service stations in Wolfsburg and Müllheim in Germany).

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