TOWARDS NET ZERO

THE ARGUMENT FOR CHOOSING HYDROGEN AND AMMONIA AS MARINE FUELS

Just as the cruise shipping industry is fully embracing LNG, the goalposts for emission control are moving. The question is, should LNG be leapfrogged in favour of zero-carbon fuels like hydrogen and ammonia?

BY **PETRISSA ECKLE PHD**

In recent years, the cruise industry has been making great efforts to reduce emissions. Its shift towards embracing LNG as the next-generation cleaner fuel is a concrete example of those efforts. Almost 50 per cent of the newbuild passenger capacity will be provided by LNG-powered ships. But LNG is no longer suitable, as it falls a long way short of the new net-zero-carbon target.

In 2018, the IMO pledged to reduce shipping emissions by at least 50 per cent by 2050 compared with 2008 levels, and to cut them completely by the end of this century. This commitment was soon deemed too conservative after the publication of a report by the Intergovernmental Panel on Climate Change (IPCC). The report highlighted the pernicious impact of 1.5°C warming and how much humanity could benefit from a more ambitious target of reaching net-zero emissions by 2050.

This target of net zero by 2050 was soon adopted by countries, cities, and companies. The EU aims to meet it by 2050, several Nordic countries hope to reach it sooner, and the State of California has committed to reaching it by 2045. Large consumer-goods companies Nestlé, Unilever, and IKEA have committed to this net-zero objective by 2050, 2040, and 2030, respectively. The shipping industry and its regulatory bodies are under intense pressure to find a feasible future-fuel solution.

With rapidly tightening regulations on greenhouse gas emissions, LNG seems to have become an obsolete energy source before it is fully mature as a marine fuel solution. For the moment LNG is still the best technological option available for powering ships, but relying on it could quickly lead to an expensive dead end for the shipping industry.

It is therefore high time to develop viable technologies, supply chains, and related infrastructure in earnest, aiming at using truly zero-carbon fuels such as hydrogen and ammonia to power ships. In fact, leading marine technology companies, together with certification and regulatory bodies, have been making progress in this direction.

Net-zero transition

About a year ago, my research team at the Sustainability in Business Lab of ETH Zurich published a report titled Towards Net Zero, commissioned by Christian Oldendorff, a German shipowner.* It argued that rather than adopting transition fuel technologies like LNG, with all their related roll-outs in supply infrastructure, the focus should be on driving the development of zero-carbon fuel technologies and applications, like those of hydrogen and ammonia, to meet the climate targets set by the Paris Agreement.

For this report, my team interviewed around 30 researchers, innovators, and experts in the maritime transport industry, and scrutinised dozens of reports, to distil what shipowners and the broader industry could do today to transition to net-zero emissions by the middle of this century.

* Eckle, P., Langguth, A., and Nahkle, C. (2019) *Towards Net Zero: Innovating for a carbon-free future of shipping in the North and Baltic Sea. Zurich. www.suslab.ch/special-shipping.html.*

The net-zero 2050 target is now widely recommended as a definitive goal for the shipping industry, and zero-carbon fuels are needed to reach it. The focus has shifted decisively to hydrogen and ammonia.

Theoretically there are four types of viable future fuels for the marine industry. LNG, which has been most in focus in recent years, addresses the emission issues relating to nitrogen oxides (NOx), sulphur oxides (SOx), and particulate matters (PM). The focus has now shifted to carbon dioxide (CO2) emissions that cause global warming. LNG, as a fossil fuel, would allow for only a maximum 20–30 per cent reduction in greenhouse gas emissions, compared, for example, to heavy fuel oil (HFO) and marine

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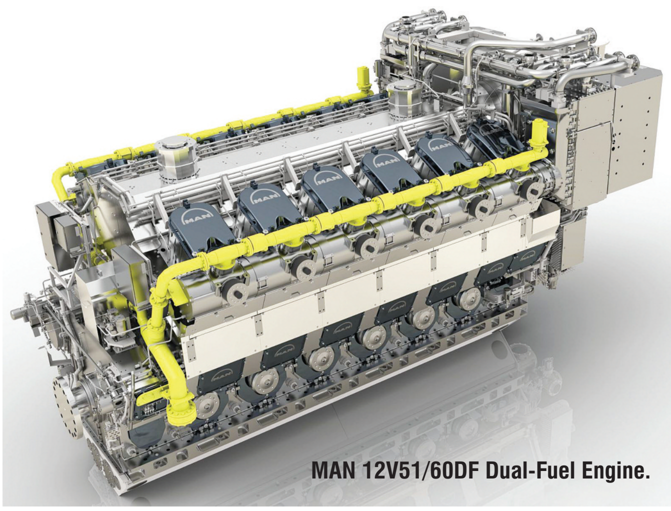
Image Courtesy: Wilhelmsen

Rendering of a first hydrogen-fuelled coastliner (ro-ro) that will also run on a 3 MW hydrogen fuel cell (and battery) from 2024.

Photo: MAN Energy Solutions SE



MAN 12V51/60DF Dual-Fuel Engine.

gas oil (MGO). With ships having life cycles of 20–40 years, this fuel is incompatible with the net-zero target.

Using the almost-carbon-neutral biofuels is another option, but one with huge uncertainty over its sustainability. Scientific models present a mixed picture of the supply of biofuels, anything from zero to fulfilling all current fuel demands. In conversations, most scientists warn about relying on biofuels and lean towards the pessimistic end of the supply estimates.

Of course, fuels could also be made from renewable electricity and would then be carbon neutral. Both biofuels and fuels from renewable electricity still emit CO_2, however, and in the case of synthetic LNG, possibly even worse, methane, during the journey.

This leaves hydrogen and ammonia as the only truly zero-carbon-fuel options that produce no CO_2 or methane during the journey. This matters, because after getting to net zero, we will need to remove carbon from the atmosphere for many more decades. Any CO_2 emitted adds to this expensive legacy, even if it comes from a carbon-neutral chain.

These are still early days. "Both ammonia and hydrogen are possible alternative fuels," said Andreas Ullrich, global market leader passenger ships & ferries, Bureau Veritas marine & offshore. "However, there is still research and development required, especially from a safety point of view."

More mature ammonia

Compared to hydrogen, ammonia entered the discussion only recently, but it could offer a faster path to scaling up; already, the whole supply chain is more mature.

It is already produced and shipped by sea at a large scale for the global fertiliser industry. Currently the world produces about 140 million tons of ammonia per year, with energy output equivalent to that of 69 million tons of MGO. This also means that equipment like pumps, tanks, and valves are readily available at an industrial scale and cost.

Hydrogen is also already produced at scale, at about 115 million tons per year, with an energy output equivalent to that of 323 million tons of MGO. But it is produced mainly from fossil fuels. Also, to transport hydrogen over long distances, it must be in liquefied form, and the infrastructure for this is not yet available at the required scale. At present, only about 130,000 tons of liquefied hydrogen are produced per year, mostly in the US, representing 0.1% of total hydrogen production.

Ammonia has another notable advantage: it requires only around three times as much storage space as MGO. Hydrogen, even in liquid form, requires around 4.3 times as much, without taking into consideration the space required for the highly insulated tanks. "Comparing ammonia and hydrogen, we might consider that ammonia, despite its toxicity, is generally easier to store and handle than hydrogen, which requires very low temperature and/or high pressure, thus making it complex and costly," said Ullrich, highlighting other difficult challenges relating to hydrogen.

Rapid strides

Although ammonia and hydrogen engines are not yet commercially available, rapid and huge strides are being made in this direction. Leading global marine technology groups like Wärtsilä and MAN Energy Solutions are at the forefront of zero-carbon engine research and development. There is still a long way to go, but substantial progress has been made.

"Wärtsilä today already has engines that are capable of running on 25 per cent hydrogen as fuel," said Maikel Arts, Wärtsilä's general manager market innovation cruise & ferry. "In 2021 we are scheduled to develop engines that are capable of running on 100 per cent hydrogen. We see that hydrogen is an important element in the decarbonisation of shipping." He described it as an "essential component" in the efforts to reach the IMO 2050 goals.

Source: Derived from Eckle et al. (2019) Towards Net Zero.

	Fuel production	Fuel distribution/ storage	Ships and engines
Ammonia	+ Two **alternative paths** with renewable electricity and natural gas (in combination with CCS) + Production **available at scale** already	+ **Transported at scale** on the sea **already** ! **No bunkering** facilities yet	+ **Dual fuel ICEs** fully commercial **within 5 years** ! **Solid oxide fuel cells** expected **in 5-10 years** – PEM need reformers ! Additional **safety measures against toxicity required**
Hydrogen	+ Two **alternative paths** with renewable electricity and natural gas (in combination with CCS) ! Liquefaction **not implemented at scale**	! **No distribution infrastructure**, very cost intensive storage ! **Bunkering facilities not yet commercial** + Sector can benefit from **hydrogen trend in road/ rail transport**	+ **Dual fuel ICEs** fully commercial **within 5 years** + **Fuel cells** expected **in 5-10 years** – benefit from fuel cell development in automotive

Both ammonia and hydrogen could provide valid solutions to decarbonise the maritime transport sector at scale within the next 10 years, but ammonia has a more mature supply chain.

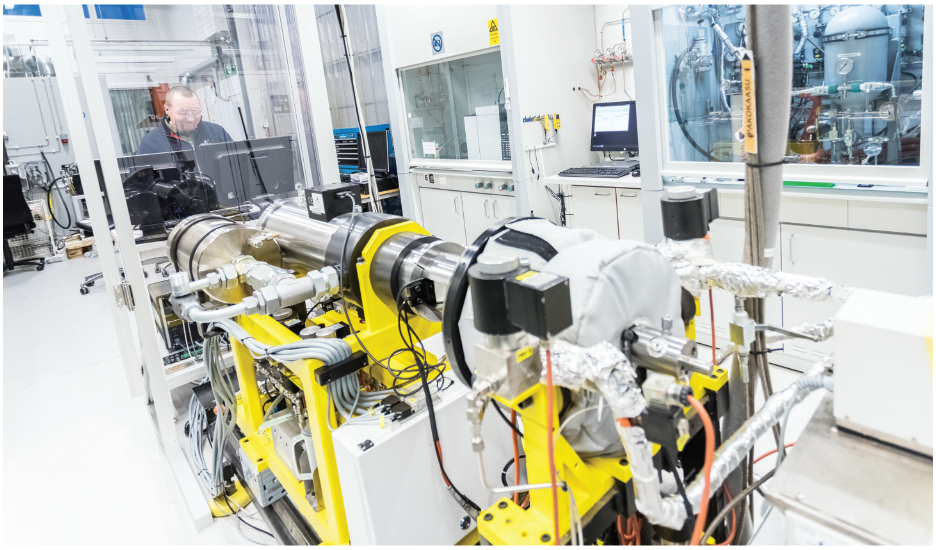
The first commercial sales of smaller-scale 2.5 MW hydrogen (dual-fuel) combustion engines have started, developed by CMB. A tugboat in the port of Antwerp will be powered by one of these engines from 2022.

Full-scale testing has started for ammonia engines. Wärtsilä and MAN are both expected to launch them commercially by 2023–24. "Wärtsilä will test four-stroke engines running on ammonia in 2021," said Arts. "It will probably take a couple of years of development before we have an engine that is ready to be launched in the market. When the market demand for ammonia engines is there and the fuel infrastructure is also simultaneously built up, Wärtsilä will be ready to serve it. So, I believe that by the middle of this decade we will have suitable products for that market."

Harnessing years of experience, MAN is also making huge strides in developing hydrogen-powered engines for the maritime transport industry. "The feasibility of such engines was demonstrated by MAN in some of its bus and truck applications already back in the 1990s," said Sokrates Tolgos, MAN's head of cruise sales and tendering. "The technology and experience gained could also be applied to a large marine four-stroke engine, which is the typical power source for cruise ships. In case of sufficient market interest, a hydrogen/diesel dual-fuel engine could be made available to the cruise market within about four to five years."

MAN has already set a firm target date for launching its first two-stroke dual-fuel engine for maritime use. "Due to firm market interest, MAN has engaged in the process of developing its first two-stroke ammonia/diesel dual-fuel engine and expects to have the first engine in service on a vessel in 2024," said Tolgos.

Safety and sustainability regulatory frameworks are also needed, and are being developed concurrently with every stage of the technical advancement. Bureau Veritas is currently developing rules for using ammonia as fuels. At the IMO level, hydrogen- and ammonia-related rules are under intense discussion. Currently, neither fuel is covered by the IGF Code.



Wärtsilä engine laboratory where various fuel types such as hydrogen and ammonia are tested.

For cruise shipping specifically, there is an added safety consideration, for which a more stringent regulatory framework is needed. Many factors, such as the toxicity and odour of ammonia, will need to be taken into consideration when developing passenger-oriented safety codes. Bureau Veritas is looking into these aspects in relation to the IGC Code and SOLAS convention.

In cruise shipping, hydrogen and ammonia technologies are also being examined from a different angle. Hydrogen fuel cells may have a greater value proposition for cruise ships than for cargo ships; they can minimise noise and vibration, for example. For this reason, the technology may find a quicker pathway to partial and initial cruise application than to freight ship adaptation.

Most cruise ships have electrified drive trains and use smaller, modular engines to generate power. Fuel cells could be added step by step, allowing for a smooth full transition to future fuels. Indeed, in October 2019, Carnival Corporation announced that in 2021 it would carry out the first hydrogen fuel cell trial, with methanol input, on board the 2018-built *AIDAnova*, an AIDA Cruises vessel.

If hydrogen is chosen as the ultimate solution, whether it will be used as a direct fuel or be converted into another type of fuel for use on board will depend, in large part, on finding commercially viable solutions for the storage and distribution of liquefied hydrogen. The quantity needed to power a cruise ship – or indeed any other deep-sea vessels – is such that hydrogen supplied in liquefied form becomes imperative.

Supplies and economics

Availability and affordability are two key issues in this net-zero undertaking. The first large-scale hydrogen projects are already in

Type	Description	Potential to reach zero-carbon
Low-carbon fossil fuels	Fossil fuels with a lower carbon footprint than conventional fossil fuels used in the shipping industry (e.g., LPG, LNG, Methanol)	Reduction by max. 20-30% vs. conventional fuels (LNG)
Carbon-neutral bio-fuels	Fuels made from organic feedstock such as oils, sugars, or waste (e.g., Bio Diesel, Bio Methane, Bio Methanol)	Can be carbon-neutral, yet, scalability of production might be limited by resource and land requirements to produce biomass – especially with growing impact of climate change on food production
Carbon-neutral hydrocarbon fuels	Synthetically produced (with the use of renewable energy and chemical compounds based on hydrogen and carbon (e.g., eDiesel, eLNG, eMethanol)	Can be carbon-neutral if produced with renewable energy and CO2 is captured
Zero-carbon fuels	Energy carriers that do not emit any CO2 to generate power (e.g., Hydrogen, Ammonia) or the direct use of electricity	Can be carbon-neutral if produced with renewable energy and does not emit CO2 under way

Source: Derived from Eckle et al. (2019) Towards Net Zero.

Zero-carbon fuels like hydrogen and ammonia do not emit CO2 throughout the lifecycle.

the planning. The German port of Hamburg, for example, is preparing to build the largest electrolyser in the world, with 100 MW of power, to produce hydrogen from renewable electricity generated offshore. The facility will be capable of producing around 2 tons of hydrogen an hour, or 17,500 tons a year if it is operated 24 hours a day.

In total, 4.6 million tons of hydrogen a year is needed to meet the existing fuel needs in the Baltic and North Sea regions. The EU recently set an ambitious target of producing 40 GW capacity of green hydrogen per year by 2030; that is 400 times the size of the eventual port of Hamburg capacity, equivalent to 7–8 million tons a year.

At the same time, the promise of a viable global hydrogen/ammonia trade is being fulfilled. Recently a $5 billion project was launched in Saudi Arabia aimed at building a facility that would use renewable energy to produce green hydrogen, which would then be processed into ammonia for export.

It is estimated that this project, when in full operation, will yield about 1.2 million tons of ammonia per year from 2025 onward. Using the Baltic and North Sea as examples again, to replace all fuels used in these regions with ammonia, 30 million tons a year would be required.

The *Towards Net Zero* report also investigated the economics of hydrogen and ammonia. It concluded that current predictions for both products vary widely, but there were strong reasons for suggesting an eventual cost parity with MGO.

Policymakers have increased their focus on bringing the costs down. The roadmap for hydrogen, recently published by the European Commission, identified technology maturity and electrolysers' economies of scale as main drivers to bring down the cost of hydrogen. Based on this, the Commission called for a rapid capacity ramp-up.

Interestingly, while fuel price is the main cost driver for current HFO and MGO engines, in the future there will be a much broader base for optimisation. Although producing fuel cells, for example, requires higher capex expenses, they have higher efficiency, smaller space requirements, significantly reduced maintenance costs (thus crew costs), and a potentially extended service life cycle through smart load management. For hydrogen, tank costs are substantial. So it could be worthwhile to consider a suitable tank capacity for the specific voyage and frequency of bunkering, aided by such solutions as bunkering automation, offshore refuelling, and containerisation of fuels.

Challenges and opportunities

The transition to a hydrogen- and ammonia-based net-zero future essentially requires building entirely new value chains, from fuel production to new engines, as well as supporting financing and business models. All of this must be achieved in the relatively short timeframe of 10–15 years – a seemingly huge undertaking.

There remain many uncertainties about the costs, technological performance, the pace at which infrastructure can be developed, future carbon prices, and which technology option will be the ultimate choice.

One key challenge is found in handling and safety – a particularly important point for the cruise shipping industry. Experts and engineers working in this field are confident that this challenge can be overcome. The toxicity of ammonia can be safely handled by applying technical measures, likewise with handling and storing hydrogen at the very challenging temperature of minus 253°C. This may require new solutions, especially at critical points, such as bunkering, where it is vital to avoid the risk of spillage.

The safety challenge, in particular, calls for full-scale pilot studies to be carried out as soon as possible in order to gain operational experience and to build trust.

The current pandemic has delayed fleet expansions. This could be a perfect opportunity to re-evaluate future fuel choice development and possibly arrive at much more future-proof zero-emission solutions for shipping.

The new focus on a green economic recovery may also lead to more funding for hydrogen and ammonia projects. In 2019 the EU ramped up innovation grants for the shipping sector. As part of the Horizon Europe 2021–2027 programme, there is €40 billion available for climate-related innovations. There are also financial supports from national and regional governments and venture capital funds, as well as finance initiatives and opportunities to transfer costs to end-customers in order to fill the funding gaps.

Having been ravaged by the current crisis, the cruise industry's top focus now is on survival. The efforts towards a zero-carbon future may be hampered and delayed, but they must remain the goal. ■

Photo: Bureau Veritas

Andreas Ullrich, business development manager for passenger ships, Bureau Veritas.

Photo: MAN Energy Solutions SE

Sokrates Tolgos, head of cruise sales & tendering, MAN Energy Solutions SE.

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