【欧州】【海事】

Maritime Issues - Utilisation of hydrogen as fuel: Maritime application of hydrogen propulsion: Progress and challenges of hydrogen fuel propulsion for different ship type projects

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【概要：Summary】

Maritime transport plays an essential role in the EU's economy, and ships are a relatively fuel-efficient means for moving freight, but fossil fuels are still the major source of energy. Therefore, shipping accounts for 13.5% of all EU's GHG emissions from transportation, and it is also responsible for about 3-4% of the EU's total CO_2 emissions.

By 2050, those emissions are expected to increase even further, from 90% to as much as 130% higher than 2008 emission levels, based on several long-term scenarios, if no mitigation measures are taken.

Considering the European Green Deal's target to reduce the transport sector's total GHG emissions by 90% by 2050, and against the backdrop of the introduction of stricter regulations on CO_2 emissions from maritime transport, fossil fuels currently used in maritime transport need to be replaced with alternative low to zero emission fuels. There exists a range of possible alternative marine fuels, including LNG, liquefied biogas, green methanol, ethanol, electric propulsion, and green hydrogen for certain ship types.

In fact, green hydrogen produced by renewable energies could be a promising alternative fuel in the shipping sector, although there still challenges like the lack of regulations related to safety and its low energy density, which requires large onboard storage capacity and extreme cooling in case of liquid hydrogen.

As EMSA's latest study on the potential of hydrogen as fuel for shipping shows, there is potential for vessels with hydrogen propulsion in particular in short sea shipping.

To demonstrate the potential of hydrogen as alternative fuel for ship and to give an overview over several projects in EU Member States and Norway, this report will present a non-exhaustive overview on projects and tests with hydrogen propulsion regarding different ship types. The analysis shows that there are mostly projects with ship types in short sea shipping, like the ferry MF Hydra in Norway, a dual-fuel engine supply ship, a crew transfer vessel, a tugboat, as well as inland barges in some EU Member States. Not all these hydrogen-powered ships seem to be in constant use, but the variety of different ship types using hydrogen propulsion underlines that there is potential for hydrogen propulsion in many ship types and functions.

Ultimately, hydrogen as alternative fuel needs to be tested for each ship type, function of vessels and distance in maritime transport or inland navigation.

【記事：Article】

1. Hydrogen as alternative fuel for ship propulsion

Maritime transport plays an essential role in the EU economy and is one of the most energy-efficient modes of transport. It accounts for around 75% of the EU' s external trade and 31% of its internal trade in terms of volume (Regulation (EU) 2023/1805). While ships are a relatively fuel-efficient means of moving freight, fossil fuels are still the major source of energy. Accordingly, shipping accounts for 13.5% of all EU' s GHG emissions from transportation and is responsible for about 3-4% of the EU' s total CO_2 emissions (Melideo/Desideri 2024). While the maritime transport sector' s GHG emissions are expected to grow with the increase in trade, by 2050, GHG emissions from shipping are expected to increase from 90% to as much as 130% higher than 2008 (Melideo/Desideri 2024).

With the introduction of the European Green Deal' s target to reduce the transport sector' s GHG emission by 90% by 2050, and the introduction of stricter regulations on CO_2 emissions from maritime transport it will be necessary to replace the fossil fuels like diesel and heavy fuel oil with alternative fuels (COM (2019) 640 final). The ship owners will have to choose the alternative fuel and technology that will be most suitable for their ship type and transport distance in maritime transport and inland navigation. Considering the lifetime of vessels of around 30 years or more, it is in fact this current decade until 2030 that will decide what level of decarbonisation the maritime transport sector will achieve by 2050.

According to the EEA and EMSA report of 2021, entitled "European Maritime Transport Environmental Report 2021 ", alternative fuels and sources of energy could be biofuels, synthetic fuels, hydrogen, ammonia, or batteries to replace conventional fossil fuels in maritime transport (EEA/EMSA 2021). In fact, ammonia and hydrogen are currently the most discussed potential alternative fuels for the shipping industry in medium and long-term (see also Antolini 2023a).

Regarding the utilisation of hydrogen-powered fuel cells or ammonia the legislative framework, including the IMO' s International Code of Safety for Ships using Gases or other Low-Flash-Point Fuels (IGF Code) will have to be amended. While in 2022, hydrogen accounted for less than 2% of Europe' s energy consumption and was primarily used to produce chemical products, the EU' s hydrogen strategy (COM(2020) 301 final) and REPowerEU plan (COM/2022/230 final) include a comprehensive framework to support the uptake of renewable and low-carbon hydrogen as alternative fuel (European Commission n.d.a).

A comparison of hydrogen (H2)' s GHG emissions in a well-to-wake (WTW) analysis with other alternative fuels has shown that hydrogen is considered being a viable alternative fuel to replace fossil fuels also on board of vessels, when being produced from renewable sources (green hydrogen) or when being produced from natural gas, using carbon capture technology (blue hydrogen) (Antolini 2023a). Only these hydrogen types are seen as solutions that could contribute to the shipping industry' s decarbonisation. Therefore, hydrogen produced by using renewable energy is expected play a key role in decarbonising sectors where other alternatives might be unfeasible or more expensive (European Commission n.d.a).

While currently, the shipping industry is still lacking the experience in a wide-spread use of hydrogen as alternative fuel, future large-scale use of hydrogen in maritime and land-based industries is expected to help decarbonising maritime transport (European Commission n.d.a).

Furthermore, as Lindstad (2020) points out there are also other challenges for the use of hydrogen in maritime transport, due to hydrogen' s low energy density and the need of building onboard storage capacity in the limited availability of space on board of vessels. Moreover, the most recent European Maritime Safety Agency (EMSA) study points out that in contrast to other alternatives like ammonia, hydrogen is also a gas with a very low flash point, and it needs secured tanks onboard of ships while liquid hydrogen requires compression to extremely low temperatures (EMSA 2023). Therefore, the costs for deploying the special infrastructure for supplying hydrogen to the shipping industry as well as retrofitting the ships or new ship construction accumulate high costs, which are currently not competitive with the costs of marine fuels.

Nevertheless, the EMSA study expects that hydrogen could become a suitable alternative fuel solution for short-sea shipping (EMSA 2023). According to EMSA, in short-sea shipping and on coastal routes, rather than deep-sea shipping, green hydrogen could be a suitable alternative fuel in maritime transport. Vessels on short-sea routes have the potential to adopt hydrogen as a fuel, because their frequency of port calls and bunkering would support lower bunker capacities once hydrogen-bunkering infrastructure becomes available (EMSA 2023). The shorter routes would thereby balance the hydrogen's disadvantage of low energy density and the need of building onboard storage capacity while having limited space available on board of vessels (EMSA 2023).

2. The EU's policy for promoting hydrogen as alternative fuel for vessels

While a shift to sustainable alternative fuels in maritime transport will be critical to achieve the GHG emission reduction targets in 2030 and in 2050, not all alternative fuels and not even the most promising candidates might lead to a (net-)zero carbon future for shipping. This is because very few alternative fuels are sustainable, environmentally friendly, and available at scale to meet the sector's growing energy demand (Antolini 2022). Besides biofuels, hydrogen and ammonia are considered as alternative fuels in maritime transport. However, their utilisation will not only require an adjustment of the EU policy on alternative fuels in maritime transport, but also an amendment of the international legislative framework, regarding safety measures, as well as the testing and introduction of new propulsion systems (Antolini 2022).

According to the EU's Hydrogen strategy for a climate neutral Europe of 8 July 2020, COM(2020) 301 final, hydrogen could become a key priority and its share in Europe's energy mix is projected to grow from the current less than 2% to 13-14% by 2050 (COM (2020)301 final). The EU Hydrogen Strategy's priority is to develop renewable, green hydrogen, produced by using renewable energies, mainly wind and solar energy. In a first phase until 2024, the Hydrogen Strategy COM (2020) 301 final sets the policy focus on laying down the regulatory framework for hydrogen with the strategic objective to install 6 GW of renewable hydrogen electrolysers (COM (2020) 301 final). In the second phase from 2025 to 2030, hydrogen needs to become part of an integrated energy system with a strategic objective to install at least 40 GW of renewable hydrogen electrolysers by 2030 and the production of up to 10 million tonnes of renewable hydrogen in the EU (COM (2020)301 final). In this phase, renewable hydrogen is expected to gradually become cost-competitive with other forms of hydrogen production (COM (2020)301 final). Regarding the role of hydrogen in the shipping industry the EU's hydrogen strategy considers a strong role for hydrogen for inland waterways and short-sea shipping (COM (2020)301 final).

In the third phase, from 2030 onwards and towards 2050, renewable hydrogen technologies should reach maturity and be deployed at large scale to reach all hard-to-decarbonise sectors where other alternatives might not be feasible or have higher costs (COM (2020)301 final). In this phase, about a quarter of renewable electricity might be used for renewable hydrogen production by 2050 (see also Antolini 2021).

Meanwhile, the EU has also launched several funding and research and innovation initiatives for hydrogen (European Commission n.d.a, DB Energy 2023). Horizon Europe can support a wide range of hydrogen actions, including research and innovation projects, applied research, technology development and integration, testing, demonstration, and validation of a small-scale prototype in a laboratory or simulated environment, innovation actions, including prototyping, testing, demonstrating, piloting, large-scale product validation and market replication, among others (European Commission n.d.b).

Horizon Europe' s Pillar II - global challenges and European industrial competitiveness - is related to hydrogen projects. It covers specifically the research and innovation partnerships between the European Commission, EU countries, industry, and other relevant stakeholders (European Commission n.d.b). The applications of hydrogen are numerous and there are two main partnerships in the field of hydrogen utilisation in transport.

The Clean Hydrogen Partnership (2021-2027) is a joint public-private partnership, proposed by the European Commission on 23 February 2021. It supports a large-scale deployment of hydrogen to achieve the EU' s climate ambition targets and builds upon its predecessor, the Fuel Cells, and Hydrogen Joint Undertaking (European Commission n.d.b, DG Energy 2023). The Clean Hydrogen Partnership is expected accelerate the development and deployment of a European value chain for clean hydrogen technologies towards a climate-neutral Europe.

Under the Horizon Europe Pillar II, there is also the framework of zero-emission waterborne transport (ZEWT), which has the aim to lead and accelerate the transformation of maritime and inland waterborne transport to eliminate GHG emissions, air and water pollutants through innovative technologies and operation (European Commission n.d.b). By 2030, the objective is to develop and demonstrate deployable zero-emission solutions which are applicable for all main ship types and services (European Commission n.d.b).

Under the framework of Zero Emission Waterborne Transport (ZEWT), hydrogen as the future fuel for ships offers an opportunity to zero the GHG emission.

Another Hydrogen Initiative, the European Clean Hydrogen Alliance brings together industry, national and local authorities, civil society, and other stakeholders (European Commission n.d.a). The alliance' s objective is to achieve an ambitious deployment of hydrogen technologies by 2030 by bringing together renewable and low-carbon hydrogen production, demand in transport and other sectors, and hydrogen transmission and distribution (European Commission n.d.a).

3. Hydrogen-powered ship projects in the EU and Norway

The testing of alternative fuels and propulsion systems in maritime transport is key to individualise the most practicable solutions and their feasibility as propulsion systems and alternative fuels for vessels (Antolini 2023b).

In recent years, the hydrogen ship projects in the EU and in Norway have increased in number and variety of ship types, demonstrating the potential of hydrogen as alternative fuel in shipping. According to the IEA' s 2022 Global Hydrogen Review 2022, there are numerous ongoing pilot and demonstration projects under the Getting to Zero Coalition (IEA 2022, Global Maritime Forum n.d.). The majority of hydrogen projects focus on small vessels, while ammonia projects on large vessels, and methanol projects split between both (IEA 2022).

Regarding hydrogen powered vessels, the launch of hydrogen ships has often been delayed by the lack of existing regulations and approvals from the authorities. The following overview includes a non-exhaustive number of hydrogen ship projects and tests undertaken in the EU or Norway with different types of hydrogen powered ships, which have been concluded in recent years or are still continuing, as operative vessels, sailing in a daily service or sporadically on certain routes.

3.1. Cargo vessel: HyShip

HyShip with the Horizon 2020 Grant agreement ID: 101007205 is a demonstrator ship powered by liquid hydrogen (Cordis 2022a). The project started on 1 January 2021 and will end on 31 December 2025. The project's total costs are set at €10,796,560.00 with an EU contribution of €7,993,942.00 (Cordis 2022a). Under the leadership of the shipping firm Wilhelmsen, the HySHIP project plans to build a zero-emission prototype cargo vessel for commercial operation running on liquid green hydrogen (Turner 2020). The EU-funded HyShip project plans also to establish a viable liquid hydrogen supply chain and a bunkering platform. The HyShip project could provide as a result the first European maritime supply chain for LH2. This is helped by having the demonstrator as one of two planned sister ships that will connect a new hydrogen production facility with LH2 demand in a series of vessels (Cordis 2022a).

3.2. Hydrogen fuel cell vessel types of pusher design and ferry design: FLAGSHIPS

The FLAGSHIPS project under the EU's Horizon 2020, with grant agreement ID: 826215, started on 1 January 2019 and will end on 31 March 2025 (Cordis 2023a). The total cost is estimated € 6,766,811.83 with an EU contribution of € 4,999,978.75 (Cordis 2023a). The FLAGSHIPS project is expected to design four and demonstrating two commercially operated hydrogen fuel cell vessels (Cordis 2023a). The vessels include two design cases, including a pusher design and a ferry design, and two demo cases, one in France (Paris) and one in Netherlands (Rotterdam). The cargo vessel, FPS Waal (FPS WAAL Cargo ship, ENI 02326484, MMSI 244650883) and the inland cargo transport vessel, Zulu06 (ENI 01841649, MMSI 226016710), are both being firsts of their kind (Hansen 2023).

The Paris demo Zulu 06 (ENI 01841649, MMSI 226016710), owned by Compagnie Fluvial de Transport (CFT), is a commercial cargo vessel operating on fuel cells and hydrogen, operating as a goods transport vessel in city centre of Paris. Zulu 06 will navigate the route between Gennevilliers and Bonneuil-Sur-Marne on the river Seine (Dokso 2023).

The Rotterdam demo vessel FPS Waal is a retrofitted container vessel transporting goods on the 240km route between Rotterdam and Duisburg on the river Rhine (Hansen 2023, Cordis 2023a). Owned and operated by Future Proof Shipping (FPS), the vessel's internal combustion engine has been replaced by a new zero-emission propulsion system, including six of Ballard's 200kW FCwave™ fuel cell modules, hydrogen storage, battery packs and an electric drive train will be installed (Hansen 2023).

Both vessels will run on hydrogen produced via electrolysis powered by renewable electricity. Being approved for safety, the ship owners expect to maintain the ships in normal commercial operation after the 18-month demonstration period of the project (Cordis 2023a).

The consortium includes 13 European partners, with three ship owners Norled (NO), Future Proof Shipping (NL) and CFT (FR) (assisted by its support companies Sogestion (FR) and Sogestran (FR)); and the fuel cell technology is provided by Ballard Europe (DK)(Dokso 2023).

3.3. sHYpS: hydrogen fuel cell propulsion systems for multiple types of vessels

The project "sHYpS" (sustainable HYdrogen powered Shipping) under the Horizon Europe programme, with grant agreement ID: 101056940, started on 1 June 2022 and will end on 31 May 2026 (Cordis 2022b). The project's total cost is estimated with €14,295,314.00 and the EU's contribution is €8,621,612.45 (Cordis 2022b).
The EU-funded sHYpS project aims to boost the uptake of clean and renewable hydrogen fuel within the maritime sector and to design and develop hydrogen fuel cell propulsion systems to power zero-emission passenger vessels (Industrial News 2023).
Researchers aim to design a hydrogen plant to ensure safe handling, containment, and usage of the fuel on board. It will develop a hydrogen-based solution, which can be adapted to multiple types of vessels (Cordis 2022b). The project will develop a (i) novel hydrogen storage intermodal 40' ISO c-type container, (ii) the complete detailed design of modular containerised powertrain based on optimised PEM Fuel Cells and (iii) their dedicated logistics. On one hand the project will define a logistic based on swapping pre-filled containers, on the other hand it will define a perspective scale-up of the storage capacity and the supply applied to the Port of Bergen. The project will use one Viking's newbuilds Ocean Cruise vessel to install the storage system onboard with the complete gas handling and energy management system and test it during the cruise by 2026, with a limited power Fuel Cell (Cordis 2022b). Viking has a building program of 6 Ocean Cruise ships by 2030 and several river ships (Cordis 2022b).

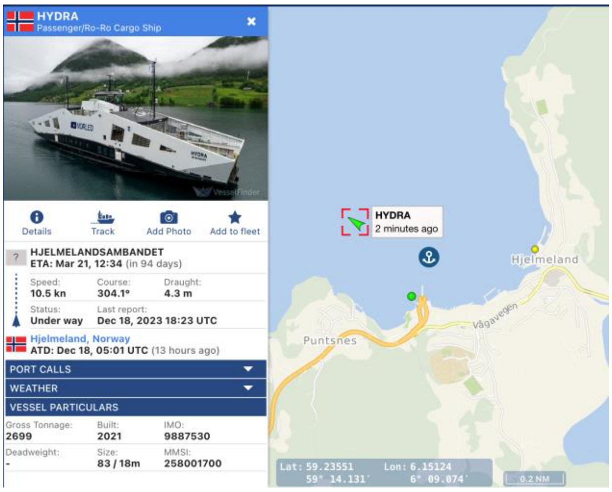
3.4. e-SHyIPS - risk and safety assessment methodologies for hydrogen implementation on passenger ships

The e-SHyIPS (Ecosystemic knowledge in Standards for Hydrogen Implementation on Passenger Ship) project, with grant agreement ID: 101007226 and total cost of €2,500,000.00, with an EU contribution of €2,500,000.00 started on 1 January 2021 and will end on 31 December 2024 (Cordis 2023b).
Since a regulatory framework applicable to hydrogen fuelled ships is not yet available, e-SHyIPS brings together the Hydrogen and maritime stakeholders and international experts, through an Advisory Board, to gather new knowledge based on regulatory framework review and experimental data on ship design, safety systems, material and components and bunkering procedures (Cordis 2023b). The approach is "vessel independent" to avoid the burdens of customized projects and is focused on the risk and safety assessment methodologies.
The e-SHyIPS project aims to define new guidelines for an effective introduction of hydrogen in the maritime passenger transport sector and foster its adoption within global and EU strategies for a clean and sustainable environment (Cordis 2023b).
The overall objective of the project includes the addressal of gaps identified in both normative and technical knowledge concerning hydrogen in the maritime transport sector. Specifically, e-SHyIPS will define and propose a pre-standardization plan for IGF code update for hydrogen-based fuel passenger ships and a roadmap to support implementation and realisation towards a hydrogen economy in the maritime sector (Cordis 2023b).

3.5. The MF Hydra liquid hydrogen-powered ferry

In Norway, the goal is to require all ferries, tourist boats and cruise ships to only operate on zero-emissions in its World Heritage fjords by 2026 and this rule is driving a major technology shift in the marine industry (Holtze 2023). The government's plan to reduce GHG emissions from domestic shipping by 50% by 2030 has also led to a commitment to build five hubs to produce hydrogen and provide the infrastructure to fuel 35-40 ships (IEA 2022). With an ambitious target to become a net-zero operator by 2040, Norled AS is currently renewing its fleet and increasing the proportion of low- and zero-emission vessels. In 2015, the company launched its first battery-powered car ferry, MF Ampere and currently, there are approximately 70 electric ferries in operation in Norway (Holtze 2023). Norled AS latest progress toward becoming a net-zero operator by 2040 is the hydrogen-powered vessel MF Hydra (The Maritime Executive 2023). It is a Passenger/Ro-Ro Cargo Ship built in 2021, began operating on 31 March 2023, sailing under the flag of Norway. It uses both batteries and liquid hydrogen fuel cells for power (The Maritime Executive 2023). The MF Hydra operates on the triangular route between Hjelmeland-Skipavik-Nesvik in Norway and can carry up to 295 passengers, 8 crew members, 80 vehicles and 10 cargo trailers (Dokso 2023, The Maritime Executive 2023, Holtze 2023).

Fig.1: MF Hyrda position on 3 January 2024



Source: https://www.vesselfinder.com/?imo=9887530, 3 January 2024

When the vessel MF HYDRA (IMO 9887530, MMSI 258001700) project started, both the technology and regulations from the classification societies and the Norwegian Maritime Authority were inadequate for hydrogen powered vessels (The Maritime Executive 2023). In fact, the MF Hydra, delivered in July 2021, was awaiting nearly two years to begin operation due to long approval time from the Norwegian authorities and DNV (IEA 2022). In April 2022, the International Maritime Organisation's (IMO) Maritime Safety Committee approved interim guidelines for the safety of ships using fuel cell power installations. For fuel storage and fuel supply to the fuel cells, the International Code of Safety for Ships Using Gases or Other Low-Flashpoint Fuel (IGF Code), originally written considering liquified natural gas, can apply to hydrogen (IEA 2022). However, specific guidelines could better facilitate wider adoption of hydrogen and hydrogen-based fuels in international shipping (IEA 2022). In case of MF Hydra, working closely with the Norwegian Maritime Authority and DNV, Norled AS and the rest of the project partners succeeded in establishing the first hydrogen propulsion regulations for the industry and the ferry entered in passenger service, following final approval from the Norwegian Marine Authority (NMA) (Holtze 2023).

3.6. Hydrocat 48 offshore tug/supply ship, crew transfer vessel

The Hydrocat 48 is a dual-fuelled hydrogen and marine gas-oil crew Offshore tug/Supply ship built in 2021, and it is operating under the flag of United Kingdom since July 2022 as part of a pilot programme in the Belgian North Sea. Based on the proven technology of the first to build a hydrogen-powered passenger shuttle in 2017, the Hydrocat 48 is dual-fuelled hydrogen in daily operation by the Antwerp Port Authority (Belgium) as crew transfer vessel CMB.TECH 2022). In dual fuel mode, considerably less CO_2 emissions are released while the load characteristics remain unchanged (CMB.TECH 2022).

3.7. Hydroville - hydrogen-powered, dual fuel combustion engines passenger vessel

Antwerp maritime group CMB launched the sea going dual fuel technology and hydrogen-powered catamaran ferry Hydroville in Antwerp in 2017 (CMB.TECH 2023, The Maritime Executive 2017). With a length of 14m, a width of 4.2m and a depth of 0.65m and a max. displacement of 14 tons, the vessel can accommodate 13 passengers and 2 crew members (The Maritime Executive 2017).

The project started as a pilot to test hydrogen technology for applications in large seagoing ships and the Hydroville is class approved by Lloyd's Register.

3.8. Hydrotug 1, the first hydrogen tugboat

The Port of Antwerp-Bruges in Belgium and CMB.TECH have launched the world's first hydrogen-powered tugboat, Hydrotug 1, which is powered by combustion engines that burn hydrogen in combination with traditional fuel (Chambers 2023b). It is the first vessel that uses the BeHydro V12 dual fuel medium speed engines. With these engines, the vessel uses clean fuels, resulting in an overall reduction of 65% of traditional fuel consumption and associated emissions in the tugboat's overall cycle. The Hydrotug 1 can store 415kg of compressed hydrogen on deck (Chambers 2023b).

3.9. The first newbuild hydrogen powered inland shipping barge Antonie

The new-build hydrogen-powered inland shipping barge named Antonie (ENI 02340008, MMSI 244030668), build at Concordia Damen by Dutch owner Lenten Scheepvaart, has been successful in conducting sea trials on 23 October 2023 (Chambers 2023a). During the trials, the ship was inspected by Lloyd's Register and received a provisional certificate to be put into service. Since the hydrogen containers were only expected to arrive by the end of 2023 and are not installed on board yet, the current testing is concentrating on the advanced diesel-electric propulsion system (Manifoldtimes 2023).

Once in service, the dry cargo vessel will transport salt for Nobian. The Lenten Scheepvaart has been shipping salt from Delfzijl to the Nobian plant in the Botlek for years, and the company turns this salt into chlor-alkali, with hydrogen as a residual product. This hydrogen produced in the chlor-alkali production process will form the clean fuel source for the Antonie. A hydrogen bunker station has now been built in Delfzijl (Chambers 2023a).

3.10. RH2IWER, Renwable Hydrogen for Inland Waterway Emission Reduction

Under the Clean Hydrogen Partnership and the Horizon Europe programme, the RH2IWER (Renwable Hydrogen for Inland Waterway Emission Reduction) project with grant agreement ID: 101101358 started on 1 March 2023 and will end on 31 August 2027 (Cordis 2023c). The EU funded the RH2IWER project, which has a total cost of €20,531,971.25, with an EU contribution of €14,998,541.38. The project aims to establish the essential foundations for the swift and efficient adoption of hydrogen fuel cells to power vessels in inland waterway shipping and, ultimately, sea fleets (Cordis 2023c). The project will conduct research, development, and demonstration of the fuel cells on a range of vessels of varying lengths of 86m, 110m and 135m and different ship types including container, bulk, and tanker vessels with installed power ranging from 0.6 to 2 MW, utilised for shipping and transport in the Rhine and Danube fleets (Cordis 2023c). Thereby, the vessels under the RH2IWER project are representative of the typical dry and liquid cargo vessels in the Rhine and Danube fleets, amounting to 12,800 vessels or roughly 80% of the inland waterway fleet (Clean Hydrogen Partnership n.d.).

The main aim of RH2IWER is to create a solid basis for the acceleration of hydrogen fuel cell powered vessels in inland waterway shipping by demonstrating six different commercially operated vessels (Clean Hydrogen Partnership n.d.). The RH2IWER project will also work with standardization of containerized fuel cell and hydrogen solutions to create a basis on which the shipping industry can significantly reduce and remove emissions from their entire fleet in the future (Clean Hydrogen Partnership n.d.).

3.11. RESHIP, energy efficiency solution for hydrogen powered ships

The project RESHIP (Redefine energy Efficiency solutions for hydrogen powered SHIPs in marine and inland waterway) under the Horizon Europe programme, with grant agreement ID: 101056815 started on 1 September 2022 and will end on 31 August 2025. It has a total cost of €3,758,912.50 and receives the full amount as EU contribution (Cordis 2022c). The EU-funded RESHIP project is expected to develop a comprehensive solution towards zero-emission waterborne transport, focusing on the development of new devices and onboard technologies (Cordis 2022c). The project aims to save energy and reduce the demands of hydrogen storage on ships and to redefine the onboard energy saving solutions for newbuilds and retrofits in marine and inland waterway in two distinct areas, Energy Saving Devices (ESDs) and onboard hydrogen utilisation (Cordis 2022c) Regarding the ESDs, the project proposes to research and develop hydrogen compatible ESD solutions in standalone/combined applications, and centres around Tubercle Assisted Propulsors (TAPs), to improve the vessel's propulsive energy efficiency and to optimise towards hydrogen power and drive system. A multidisciplinary consortium of the RESHIP project aims to develop, demonstrate, and validate technologies to achieve a minimum overall 35% energy saving and halving the hydrogen storage demands on space and/or weight,(Cordis 2022c).

3.12. Planning and development of other hydrogen powered vessels

With the hydrogen technologies being now mature and the liquid hydrogen storage mastered, the deployment of liquefiers around the world, and the latest generations of mass-produced fuel cells, there are more ships with hydrogen propulsion in planning and development, also for multipurpose cargo ships of about 5,000 tons deadweight (Energy Observer 2022). According to Energy Observer (n.d.), this new multipurpose cargo vessel Energy Observer 2 is first full-scale demonstrator with specifications that have been established according to the urgent need to renew the fleets of multipurpose cargo ships of about 5,000 tons deadweight, used on intra-continental and coastal routes (Energy Observer 2022). The main features of Energy Observer 2 are Length: 120 meters, Width: 22 meters, Draft: 5,5 meters; Deadweight: 5,000 tons; Containers: 240 TEU (Twenty feet equivalent), Commercial speed: 12 knots, Electric propulsion: 4 MW, Fuel cell power (RexH2 EODev): 2.5 MW, Liquid hydrogen tanks (LH2): 70 tons (1000 m3), Range: up to 4,000 nautical miles (Energy Observer 2022).

The cargo vessel Energy Observer 2's four propulsion sails (Oceanwings) with a total surface area of 1,450m2 will reduce energy consumption by 15 to 30%, depending on the angle and the force of the wind (Energy Observer n.d.). Thereby, Energy Observer 2 will be the first hydrogen-powered, zero-emission vessel to be self-sufficient in energy (Energy Observer 2022). Furthermore, the Norwegian shipping company Egil Ulvan Rederi, plans to build the "world's first zero-emission bulk carrier" (Hakirevic Prevljak 2022). The first zero-emission bulk carrier Orca is scheduled for completion and commissioning in 2024. The plan is to transport aggregates products for HeidelbergCement and grain for partner Felleskjøpet from West Norway to East Norway, and vice versa, using emission-free transport (Hakirevic Prevljak 2022).

The ship will be highly energy-efficient with a streamlined design to reduce energy consumption, equipped with a hydrogen combustion engine and Flettner rotor sails, as well as a hydrogen fuel cell and battery, to ensure optimal operation during loading and unloading operations (Hakirevic Prevljak 2022).

Moreover, ABB will deliver complete power, propulsion, and automation systems for Samskip Group's hydrogen-powered container vessels (ABB 2023). The compact ABB Onboard DC Grid™ power distribution system provides improved performance, efficiency, and system safety (ABB 2023). Furthermore, the global logistics company Samskip Group headquartered in Rotterdam, Netherlands plans to build two newbuild short-sea container ships with hydrogen as a fuel (ABB 2023). Built by Cochin Shipyard Ltd, the largest shipbuilding and maintenance facility in India, the 135-meter ships are due for delivery in Q3 and Q4 of 2025, respectively (ABB 2023). Both vessels will be operating between Oslo Fjord and Rotterdam, approximately 700 nautical miles distance (ABB 2023).

Samskip's vessels will be powered by a 3.2 MW hydrogen fuel cell each, with diesel generators installed for back-up. The logistics group anticipates that each vessel will be able to avoid around 25,000 tons of CO_2 emissions a year when powered by fuel cells and by using green shore power at the port of call (ABB 2023).

The project is co-funded by Norwegian state enterprise ENOVA under Norway's Ministry of Climate and Environment (ABB 2023).

Another project for hydrogen powered ships is the Norwegian shortsea liner Viasea Shipping's project to build a pair of hydrogen-powered containerships for operation on Viasea's routes between Norway and northern Europe (Ajdin 2023). The two ships will initially operate on a combination of hydrogen and diesel, equipped with two large rotor sails, a battery pack, and a range of other energy-efficient measures (Ajdin 2023). The combination of hydrogen and diesel is expected to lower CO_2 emissions by more than 75% compared to an equivalent diesel-powered ship (Ajdin 2023).

Norwegian state enterprise ENOVA supports the project with $65.6 million. Hydrogen bunkering is currently planned in Norway, but as hydrogen becomes available at more locations along the planned route, the ships could be able to operate entirely without diesel.

Moreover, the Cruise Division of MSC Group confirmed on 21 September 2023 that it ordered at Fincantieri two new hydrogen-powered ships EXPLORA V and EXPLORA VI to join the fleet of its luxury travel brand Explora Journeys in 2027 and 2028, respectively (Fincantieri 2023). The two new ships will use of liquid hydrogen with fuel cells for their hotel operations while docked in ports to eliminate carbon emissions with the vessels' engines switched off (Fincantieri 2023). The ships will also feature a new generation of LNG engines that will further tackle the issue of methane slip with the use of containment systems.

The Cruise Division of MSC Group also pledged to continue its push towards a net zero-carbon emissions target by 2050 by investigating additional environmental technologies for its ships (Fincantieri 2023).

4. Conclusion

The decarbonisation of the transport sector, including the maritime transport, is a key target for reaching climate neutrality by 2050.

In the shipping sector, besides the cost of development of the hydrogen-based power supply onboard of a ship, including the need to consider the challenges of storing hydrogen onboard of ships, the lack of existing guidelines or safety standards for using hydrogen fuel cell power installations onboard of ships delays the approval processes, as seen in case of the MF Hydra in Norway. The operation in domestic waters is possible also without the existence of international rules, but each country, where hydrogen powered ships are set to operate, needs to introduce specific safety standards. At international level, in April 2022, the IMO's Maritime Safety Committee approved interim guidelines for the fuel storage and fuel supply to fuel cells, under the IGF Code.

The Hydra ferry's Ballard's FCwave™ 200kw fuel cell modules were the first to achieve type approval from both classification societies, DNV and Lloyd's Register for marine operations and reached final approval from the Norwegian Marine Authority (NMA) after two years approval process. Therefore, besides the technical and operational requirements of hydrogen powered vessels, the type-approval of fuel cell modules, and the approval of hydrogen powered ships themselves are a major challenge. The EU and IMO need to introduce regulations for these new types of motors and hydrogen systems.

As the non-exhaustive list examples for hydrogen powered ships shows, there are manifold projects on the way, as demonstrator ships or already in service, with many different ship types and tasks in freight and passenger transport. This list of different ship types with hydrogen propulsion shows that hydrogen propulsion systems can be applied in many different ship types and functions, and even for longer distances like the Energy Observer 2 range of 4,000 nautical miles shows. The results of this wide variety of projects of different ship types with hydrogen propulsion or dual fuel solutions will show in the next years whether hydrogen or another alternative fuel for maritime transport will be the best solution. Ultimately, for each ship type, function, and distance, in passenger ships or cargo vessels, an individual and specific zero-emission alternative fuel solution needs to be found.

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