Towards advanced maritime fuel cells

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Hydrogen and hydrogen-derived fuels are expected to play a critical role as future energy vectors for maritime applications, as clearly stated in the EU Hydrogen Strategy. Fuel cells, particularly proton exchange membrane fuel cells (PEMFCs), utilizing hydrogen or hydrogen derivatives, have emerged as promising alternatives to conventional combustion engines, offering high efficiencies, lower emissions, and quiet operation. However, maritime applications require higher power and much longer lifetimes than those developed and achieved so far by state-of-the-art fuel cell stacks and systems.

Two EU-backed projects (both supported by the Clean Hydrogen Partnership and its members Hydrogen Europe and Hydrogen Europe Research), H_2MARINE and MiNaMi, are currently pioneering the next generation of high-power PEMFCs by addressing the dual challenges of power density and durability, providing the maritime sector with a viable roadmap for the multi-megawatt era.

H_2MARINE

The H_2MARINE project is a 42-month initiative co-funded by the EU and the Swiss State Secretariat for Education, Research, and Innovation (SERI). It is implemented by 13 partners from academia, research, and the commercial & maritime sectors. H_2MARINE aims to design, test, and validate two PEM stacks capable of generating 250-300 kW of electric power for marine applications.

Adopting a top-down approach, the project builds on the proof of concept of two PEM stacks and will identify testing requirements, operating conditions, and load curves in collaboration with key stakeholders from the shipping industry. The overarching objective is to define end-user needs, maritime operating environments, and test conditions, while also evaluating diagnostic tools for stack performance, overall system integrity, and the health prognosis of critical components. By optimizing the design of stack modules for future up-scaling to 10MW powertrain systems, H_2MARINE aims to advance fuel cell technology and support the transition toward cleaner and more sustainable maritime transport.

The technical targets of H_2MARINE focus on designing and building two different PEM stacks (by Powercell Group and EH Group) generating 250-300 kW for marine vessels, while achieving a stack lifetime of 40,000 to 80,000 operating hours in line with the targets set by the Clean Hydrogen Partnership. The project also seeks to improve system integrity and the health monitoring of critical components through enhanced diagnostics and testing. Scalability remains a core priority, with flexible design concepts adaptable to different power needs and targeting systems of up to 10MW. Cost efficiency is another defining purpose, with a CAPEX target of €1,000/kW by 2030.

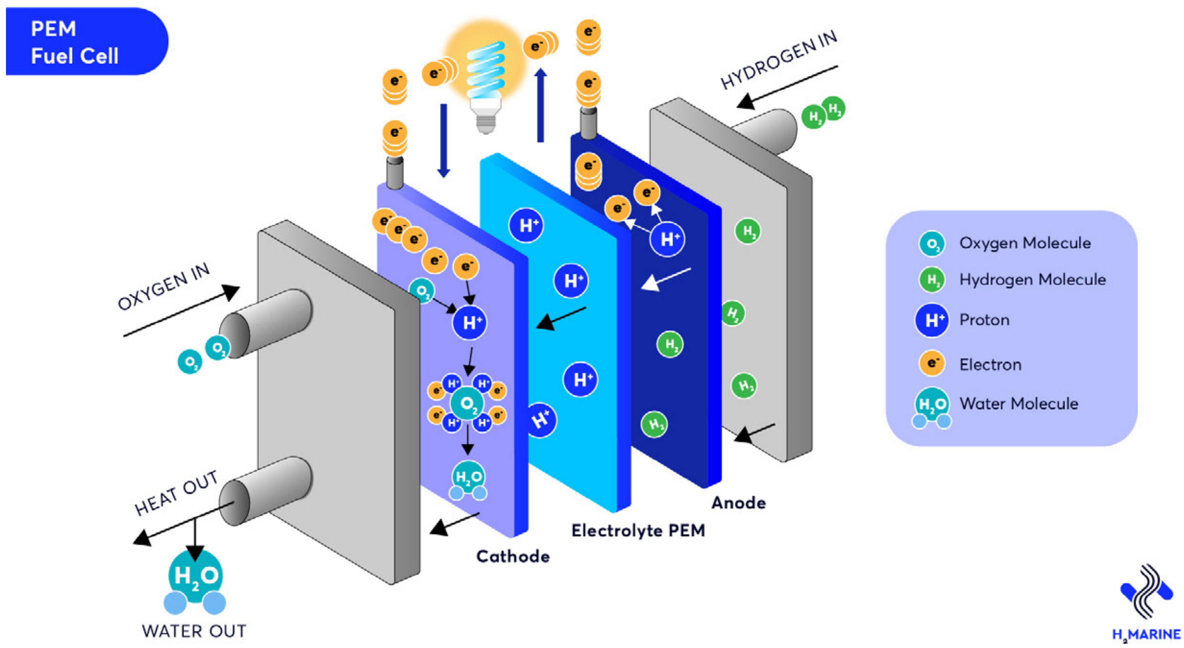
Through the assessment of the technical and economic feasibility of the proposed solutions, the partners will be able to identify promising end uses, potential markets, and the most attractive opportunities. The project is designed to test these solutions in a relevant environment that closely reflects actual implementation conditions, ensuring that the results are robust and applicable to the global maritime sector.

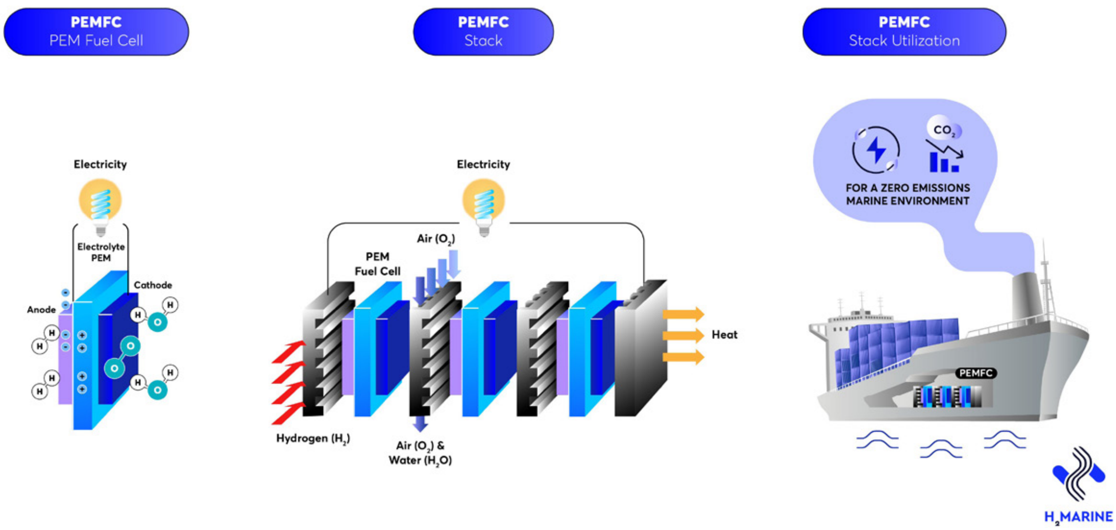
MiNaMi

Following H_2MARINE (and using one of the stacks developed within it), the **MiNaMi project** (development of 'Million Nautical Mile' fuel cell systems for the shipping industry) aims to develop a megawatt-scale PEMFC system, focusing strongly on durability. Rather than simply scaling up existing technology, the project integrates advanced sensing and smart-power electronics to minimize hydrogen losses and extend the system's lifetime to more than one million nautical miles.

The principal ambition is to develop the first megawatt-scale PEMFC system for maritime use, capable of operating over one million nautical miles at a speed of 12.5 knots. The system and its associated power electronics are being designed as modular building blocks for fuel cell installations exceeding 10 MW, opening the way for new maritime applications. Meanwhile, the use of the latest stack technology developed in H_2Marine is expected to reduce the system's footprint, increasing the usable on-board volume for fuel, cargo, and passengers.

The expected results of MiNaMi include the development of a MW-scale PEMFC module with durability above 80,000 operating hours in relevant maritime applications, while targeting a maritime system CAPEX below €1,000/kW. The project also aims to maximize hydrogen utilization and minimize hydrogen emissions to the atmosphere, both of which are essential for improving





the environmental and economic performance of hydrogen-powered vessels.

Although its primary focus is maritime transport, the multi-stack solutions developed within MiNaMi can also be applied to other MW-scale PEMFC applications, including trains, mine trucks, and peak-power plants supporting the electricity grid. In this way, the project contributes not only to maritime decarbonization but also to the wider deployment of hydrogen technologies in sectors where direct electrification may not be sufficient. Through the advancement of durable and modular megawatt-scale PEMFC systems, MiNaMi supports Europe's ambition to maintain a leading position in the development of efficient fuel cell technologies.

Increasing (green) competitiveness

Taken together, H_2MARINE and MiNaMi address two closely connected challenges on the path toward zero-emission shipping. The former focuses on the design, testing, validation, diagnostics, and health monitoring of PEMFC stacks for marine applications, helping to establish the technical foundations needed for reliable MW-scale maritime deployment. The latter builds on this direction by targeting the development of durable MW-scale fuel cell systems, with an emphasis on long operating lifetimes, hydrogen efficiency, and modular designs that can be scaled beyond 10 MW.

Their combined output is expected to strengthen the entire development pathway of maritime PEMFCs, from stack-level innovation and system integrity assessment to large-scale system integration and long-term operation under realistic marine conditions. The broader impact extends beyond technology development alone – the improvement in power density, durability, diagnostics, and scalability will help increase the competitiveness of PEMFCs against fossil- and synthetic-fuel-based solutions, especially in applications where weight, volume, and operating efficiency are critical. Lastly, the projects are also expected to strengthen European fuel cell manufacturing, stimulate innovation across the hydrogen and maritime value chains, and support supply chain development, type approval, and future market uptake. □