

Maritime Summary Note n°238 – February 2022

« Hydrogen and the maritime sector »

The drive to green the maritime sector is pushing industrialists, shipowners, and port authorities to find or "re-discover" alternative energy sources that have occasionally been sidelined by our mono-carbon societies. This is the case, for instance, with the utilization of dihydrogen (H₂), more commonly known as hydrogen, as an energy vector. Identified as early as the 18th century, it represents one of the primary pathways toward decarbonization. Within the maritime sector, hydrogen will serve both as a fuel for propulsion and as a source of electricity through hydrogen fuel cells. Numerous challenges remain to be tackled, such as safety constraints, achieving carbon neutrality from "extraction" to consumption, and maintaining economic sustainability. What are the current developments required to integrate hydrogen into tomorrow's energy mix?

Context and operating environment

In 2018, global annual hydrogen production was estimated at 75 Mt. It is primarily utilized to supply the chemical and refining industries, with nearly 45% absorbed by petroleum refining (for desulfurization) and almost an equal share dedicated to the production of ammonia and nitrogen fertilizers. Approximately 10% is channeled into the food, electronics, and metallurgical industries, while nearly 1% is allocated to space propulsion for rockets through the combustion of liquid hydrogen and liquid oxygen. Hydrogen does not exist on Earth as a directly available primary energy source like coal or crude oil. In its H₂ molecular form, it acts solely as an energy vector that must be produced by extracting it from its constituent compounds (water, methane, biomass, etc.). It can then react powerfully with oxidants, particularly oxygen, releasing significant amounts of energy. Hydrogen possesses an exceptionally high gravimetric energy density: 1 kg of hydrogen contains as much energy as approximately 3 kg of oil. However, hydrogen is an extremely light gas that occupies a massive volume under standard atmospheric pressure conditions. This volume must be drastically reduced to enable viable transport and storage. The H₂ molecule can be liquefied at atmospheric pressure at an extremely low temperature (**-253°C**), though this process carries a high energy cost and demands heavy capital investments in specialized cryogenic equipment. Furthermore, a continuous boil-off phenomenon occurs due to hydrogen warming.

Cryogenic liquid storage is utilized for onboard transport or for managing large volumes of hydrogen. The most mature market today remains the aerospace sector, which stands as the largest consumer of liquid hydrogen, notably for launching shuttles and rockets since 1979.

Another alternative, and currently the most widespread, consists of compressing hydrogen at very high pressures (200, 350, or 700 bars), while strictly mitigating leak, corrosion, and explosion hazards. This method requires massive storage tanks, thereby excluding smaller vessels. For context, a pressure of 700 bars represents 700 times standard atmospheric pressure.

Steam methane reforming (SMR) from fossil fuels (coal, natural gas, oil) remains the most widespread production method (94% of global volume) because it is by far the most economical. Evaluated at €1.5/kg, its production cost per kilogram remains triple that of natural gas excluding carbon taxes, and without factoring in its heavy environmental footprint. This technique releases massive amounts of CO₂: for every tonne of hydrogen produced, 10 to 11 tonnes of CO₂ are generated and typically emitted into the atmosphere. To lower costs, infrastructure projects would need to deploy several tens of megawatts right from the initial phase.

Highly carbon-intensive, this technique is doomed to phase out in the short to medium term unless the carbon is captured and subsequently sequestered (CCS — *Carbon Capture and Storage*) or utilized (CCU — *Carbon Capture and Utilization*). CCS technology consists of capturing CO₂ directly at its production source and injecting it into depleted oil and gas reservoirs or deep saline aquifers. However,

optimal geological conditions are rare and far from matching global requirements. While it could drastically reduce industrial atmospheric CO₂ emissions, this solution remains highly expensive and not entirely proven. CCU technology is still in an embryonic stage and has yet to be validated from an economic and environmental standpoint. It is being envisioned for microalgae cultivation and the production of urea, salicylic acid, or synthetic methane. Currently, nine European countries are working on developing future CCU applications with a cumulative total of 24 projects. These technologies are not fully mature and could even present hazards in the event of seismic activity, which could trigger fractures in underground cavities and inadvertently release the sequestered gas into the atmosphere. Steam methane reforming must be substituted by alternative decarbonized processes, such as green hydrogen production derived from alkaline water electrolysis¹, biomass conversion, or thermochemical cycles. Nevertheless, production costs today remain prohibitive. At the production gate, the cost of hydrogen derived from electrolysis² is estimated between €4 and €14/kg. According to ADEME, hydrogen would become competitive only if sold at a price below €6 to €7/kg at the production gate, and €9/kg at the pump. A massive scaling up is therefore indispensable.

Terminology and classification codes

- **Green or renewable hydrogen** is produced through the electrolysis of water, utilizing electricity derived exclusively from renewable energy sources.
- **Grey or fossil-fuel hydrogen** is produced through thermochemical processes, utilizing fossil fuels (such as coal or natural gas) as primary raw materials.
- **Blue or low-carbon hydrogen** is produced in the exact same manner as grey hydrogen, with the crucial difference that the CO₂ emitted during the manufacturing process is captured to be either reused or sequestered.
- **Yellow or low-carbon hydrogen** (a classification more specific to France) is produced through water electrolysis similar to green hydrogen, but the electricity supply is primarily derived from nuclear energy.

Beyond the economic aspects of low-carbon hydrogen, alternative factors must be taken into internal accounting, notably risk management: hydrogen can be highly flammable, corrosive, and toxic. Consequently, crew training must be significantly reinforced. The molecule poses severe operational challenges tied to vessel autonomy, high-pressure maintenance, reliance on cryogenic technologies, and corrosion. Hydrogen demands massive storage volumes. Its distribution requires the existence of a robust regional infrastructure network for its transport—executed via trucks carrying gaseous or liquid hydrogen, through pipelines, or by sea—alongside heavy shoreside investments in refueling distribution systems.

The development of hydrogen as an alternative energy vector is accompanied by public subsidies on both regional and national scales, designed to "de-risk" this technology which currently remains largely unproven across the world. Aligning with the strategic guidelines set forth by the European **Green Deal**, numerous States have explicitly integrated hydrogen within their national economic stimulus packages.

European Union initiatives

In compliance with the Green Deal objectives to slash greenhouse gas (GHG) emissions by 55%, the European Union (EU) aims to foster a unified European hydrogen market. The EU roadmap projects 40 GW of renewable hydrogen production (10 Mt) by 2030. The share of hydrogen is slated to reach 40% of the European energy mix by 2050. The EU enshrines H₂ as a pivotal technology capable of achieving climate targets while acting as a major generator of employment. To catalyze this eco-energetic transition, dedicated European funds have been established. This includes the European framework program for research and innovation, Horizon Europe, operating with a €95 billion budget for the 2021–2027 period. The Innovation Fund represents another program financed by carbon market revenues, designed to support low-carbon technologies at the demonstration and pilot stages. This fund could reach €10 billion over ten years, focusing its action areas on Carbon Capture,

¹ Water electrolysis is a method that aims to separate the water molecule into hydrogen and oxygen through the application of an electric current. The process itself does not emit any CO₂.

² Source : IRENA "Green hydrogen cost" 2020.

Utilization, and Storage (CCUS), renewable energy production, and energy storage technologies. Alternative financing mechanisms include InvestEU, backed by a €372 billion budget.

The Connecting Europe Facility (CEF) stands as a dedicated funding program for energy and transport infrastructure studies and works in Europe. The financed projects are inherently cross-border and cover identified priority corridors across energy (operating with a €5.84 billion budget), transport (€25.81 billion budget), and digital infrastructure (€2.07 billion budget). Finally, the ultimate EU financing tool that H2 projects can claim is the *Interregional Innovation Investments (I3) Instrument*, endowed with €75 million and dedicated to the green transition, digital integration, and smart, sustainable industrial processes.

Many European nations capitalized on post-Covid budgetary efforts to formalize the rollout of their national hydrogen sectors through strategic stimulus plans extending up to 2030³. The European Clean Hydrogen Alliance serves to organize and coordinate the collective efforts of Member States and various industrial actors on this theme, a framework to which France actively contributes. Several Member States, including Germany and Portugal, have already outlined their national hydrogen strategies, while others are scheduled to do so in the near future.

The EU counts approximately 250 active or envisioned hydrogen-related projects, 20 of which directly concern the maritime sector. Maritime and inland ports act as critical, highly favorable nerve centers for the expansion of the H2 sector, due to the presence of dense industrial clusters where operational synergies can be unlocked. Ports concentrate both production and distribution units while acting as potential demonstrators and users of H2 solutions, which branch out into shoreside (road and rail transport), maritime, and inland waterway applications.

On land, this primarily concerns cargo handling equipment: reach stackers, straddle carriers (*cavaliers*), stackers, loaders, tractors, and excavators, alongside forklifts that are indispensable to port operations but whose hydrogen applications remain embryonic. At sea, port service vessels represent a wide range of use cases and operations (dredgers, barges, tugs, pilot boats, etc.). However, it is observed that purely maritime projects currently focus on small-scale vessels, such as passenger or freight shuttles—even though a pusher boat, a tug, and an H2 ferry are actively under study within the EU. Around fifteen vessel projects are currently underway. Among these fifteen configurations, the project backed by the Danish shipowner DFDS stands out as the most ambitious, featuring the construction of a mega-ferry powered by hydrogen fuel cell (FC) technology, designed to accommodate 1,800 passengers alongside 120 trucks or 380 cars. It would operate with a 48-hour autonomy—the transit time required for its liner service between Copenhagen and Oslo—with delivery slated for 2027.

Certain applications utilize *dual-fuel* internal combustion engines that burn hydrogen while injecting a small quantity of diesel. This configuration is deployed on vessels requiring high power outputs that fuel cells cannot yet deliver. Hydrogen can also be combined to synthesize e-fuels suitable for larger vessel segments (container ships, bulk carriers, etc.).

Large-scale H2 projects that frequently integrate into a circular economy loop involve major industrial-port complexes, such as the Port of Rotterdam. The oil major BP and the chemical corporation Nouryon intend to convert a refinery that currently utilizes fossil-derived hydrogen over to green hydrogen, a transition that could reduce CO2 emissions by 350,000 tonnes per year. The corporate agreement provides for a 250 MW water electrolysis plant capable of producing up to 45,000 tonnes of green hydrogen per year, which would establish it as the largest facility of its kind in Europe. To generalize green hydrogen as a mainstream maritime propulsion vector, a comprehensive network of bunkering stations coupled with greenfield storage systems must be established. The Port of Rotterdam aims to become a core H2 hub on both European and global scales. By 2030, port authorities project the production of 1.16 Mt of H2 per year through CCUS and electrolysis. The German energy corporation Uniper and the port authority concluded a strategic agreement to develop a production capacity of 100 MW, expanding to 500 MW of green hydrogen by 2025 on Uniper's site at *Maasvlakte*. The hydrogen plant would utilize electricity generated by offshore wind farms in the North Sea. Uniper's hydrogen facility will be directly connected to the future HyTransport.RTM pipeline crossing the Port of Rotterdam. The pipeline will also link Uniper's plant to the national hydrogen infrastructure and the Delta Corridor pipeline bundle. This latter project is designed to supply hydrogen to the chemical clusters of Moerdijk and Geleen (Chemelot), and further inland into North Rhine-Westphalia. The Port of Rotterdam functions as a vital energy hub for Western Europe: today, approximately 13% of the European energy supply enters the European Union via Rotterdam. The port targets absolute carbon neutrality by 2050 while preserving its central role within the European

³ Germany intends to inject €9 billion, France €7.2 billion over the next ten years, Portugal €5 billion, Spain €8.2 billion, the Netherlands €9 billion, and the United Kingdom £12 billion.

energy architecture. By then, according to port authority expectations, approximately 20 Mt of hydrogen will transit through the port annually to supply the Netherlands, Germany, and Northwest Europe.

The Port of Antwerp is also multiplying H2 projects in partnership with several industrial leaders such as Engie, Fluxys, Indaver, and Inovyn. The port ordered the world's very first hydrogen-powered tugboat, named the *Hydrotug*, from the Compagnie Maritime Belge (CMB). This unique *Hydrotug* is driven by internal combustion engines running on hydrogen in combination with diesel. In June 2021, CMB also commissioned a refueling station supplying H2 produced via a 1.2 MW electrolyzer. This station can simultaneously supply heavy goods vehicles, ships, harbor crafts, and buses. CMB also designed a dual-fuel truck operating on an H2-diesel mix.

The Port of Hamburg capitalizes on collective intelligence through the rollout of the "Hamburg Hydrogen Network," a coalition notably composed of Shell, Vattenfall, and Mitsubishi Heavy Industries. This alliance secured EU support for nine complementary projects integrating H2 production, distribution, and utilization. The target is to reduce CO2 emissions by 16 million tonnes per year by 2030 while concurrently producing 1 Mt of H2, with the ultimate objective of substituting fossil fuels across industry, transport, and logistics.

Projects in France

France produces approximately 900,000 tonnes of industrial hydrogen per year for petroleum refining and heavy chemicals, representing 1.5% of global production. For scale, the United States and China each produce 10 Mt per year. The national strategy for the development of decarbonized hydrogen in France relies on a public subsidy framework of €7.2 billion (funded through *France Relance* and *Investissements d'Avenir*) spanning a 10-year period. A tranche of €3.4 billion was allocated over the initial three years from 2020 to 2023, followed by a progressive rollout of €3.8 billion from 2023 to 2030. Priority is given to industrial decarbonization by fostering the emergence of an electrolysis manufacturing sector, targeting a milestone of 6.5 GW of installed electrolyzer capacity by 2030. This will prevent the atmospheric release of 6 Mt of CO2 each year. In 2020, only 5 MW of electrolysis capacity had been deployed.

The second core strategic axis focuses on heavy mobility (public transport, freight transport) utilizing low-carbon H2. The final axis centers on expanding R&D across H2 production, transport, storage, and end-use applications, which will generate significant employment. A National Hydrogen Council (*Conseil national de l'hydrogène*) was established a year ago to streamline exchanges between the State and the various industrial sectors involved. Its corporate members include McPhy, EDF, Engie, TotalEnergies, ArcelorMittal France, Airbus, Faurecia, Alstom, Vicat, Air Liquide, and the CEA. The goal is to achieve a rapid shift to industrial scale to drive down production costs. According to the national strategy, the objective is to generate 50,000 to 150,000 direct or indirect jobs. This strategy is also integrated within a cooperation framework with European partners to co-finance a unified European hydrogen value chain.

TotalEnergies and Engie partnered within the "Masshyla" project, which targets H2 production derived from solar photovoltaic energy (with a global capacity exceeding 100 MW) to initially supply TotalEnergies' La Mède biorefinery in the Fos-sur-Mer industrial-port zone, substituting legacy steam methane reforming. The goal is to produce 5 tonnes of hydrogen per day. For 2022, a hydrogen station will supply an initial fleet of eight specially designed 44-tonne trucks. Constructed under the HyAMMED framework (*Hydrogène à Aix-Marseille pour une Mobilité Écologique et Durable*), this project is partly financed by ADEME and integrated into the European *H2Haul* program. This refueling station will also benefit from support from the *Région Sud* and Europe through the Clean Hydrogen Partnership (FCH JU — *Fuel Cells and Hydrogen Joint Undertaking*). Built and operated by Air Liquide, the station will eventually be capable of supplying up to 20 trucks. Other project partners include transport operators and major mass retail corporations such as Carrefour, Coca-Cola European Partners, and Monoprix.

Hydrogen is also being actively studied for inter-urban mobility. Several projects are currently underway, such as in Vannes with the "Hylas" hydrogen shuttle, designed to accommodate 250 passengers, and in Toulon with the "Hynovar" project, focused on an H2 refueling infrastructure for a maritime passenger shuttle. This latter initiative, led notably by the Var Chamber of Commerce and Industry (CCI du Var), Engie Cofely, and Hyseas, encompasses the construction of a vessel, the rollout of a hydrogen station equipped with an electrolyzer, and infrastructures designed to pool shoreside (bus) and maritime applications. In Nantes, operating since 2018, the "Jules Verne 2" waterbus (10 kW) navigates the Erdre

River powered by a hydrogen fuel cell (FC). As the backer of this H2 Navibus project, Semitan (the municipal transit authority for the Nantes metropolitan area) formed a consortium of seven partners (MH2, Bureau Veritas, Polytech Nantes, Matis Technologies, Ship-ST, and Naval), securing financial support from the Region and the Metropolis. The global budget amounts to nearly €1.6 million, including close to €597,000 for the vessel alone.

Under the framework of the European "Flagships" program, the *Compagnie Fluviale de Transport* (CFT)—a subsidiary of the Le Havre-based Sogestran Group—transposed to Paris its inland waterway vessel project originally intended for the Lyon metropolitan area. This river unit deployed on the Seine will be dedicated to transporting pallets and containers across Paris. *Flagships* stands as a multidisciplinary European research program gathering industrial partners, shipowners, maritime equipment manufacturers, power system designers, and fuel cell suppliers. Supported by the EU, it provides funding to help pioneer new operational concepts. The project is backed by a financial allocation from the Clean Hydrogen Partnership (FCH JU) with a €7 million budget dedicated to the construction of two vessels. The twin project involves the construction of a passenger ferry within the shipyards of Stavanger, Norway.

Ultimately, no alternative fuel is in a position to substitute petroleum by 2030 for transoceanic voyages due to a profound lack of technological maturity, storage constraints, and supply chain or bunkering logistics bottlenecks. Alternative fuels multiply the cost of energy on board by a factor of two to eight, an item that already accounts for 20% to 30% of a shipowner's annual operating expenses. Nevertheless, room for hope remains through the numerous European economic stimulus packages and the emerging corporate synergies between stakeholders, driving forward the decarbonization of our global maritime activities.

Camille VALERO

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