REPowerEU and the Hydrogen Gamble: Ambitions, Challenges, and the Road Ahead

Paolo Blecich[1,*], Josip Batista[1], Mateo Kirinčić[1], Fran Torbarina[2]
Faculty of Engineering, University of Rijeka, Croatia[1]
Faculty of Maritime Studies, University of Rijeka, Croatia[2]
paolo.blecich@riteh.uniri.hr

Abstract: *The European Union's REPowerEU strategy places green hydrogen at the center of its plan to eliminate fossil fuels and accelerate the green transition. The strategy targets 20 million tonnes (MTPA) of green hydrogen per year by 2030: 10 MTPA to be produced domestically and 10 MTPA imported. Achieving this requires scaling electrolysis capacity from the current 0.3 GW to 120 GW, a remarkably ambitious, if not unrealistic, target. Current green hydrogen production costs range from 100 to 200 €/MWh, several times higher than natural gas prices, which fluctuate between 20 and 40 €/MWh. In contrast, blue hydrogen, which is produced through natural gas reforming combined with carbon capture and storage (CCS), generally costs between 50 and 100 €/MWh. To bridge the cost gap between hydrogen and fossil fuels, the EU established the Hydrogen Bank with €3 billion to kick-start the market through competitive funding mechanisms. The REPowerEU hydrogen targets have drawn criticism due to limited availability of renewable electricity, underdeveloped infrastructure, and the slow pace of electrolysis deployment. Concerns also focus on the inefficiency of hydrogen use in sectors such as passenger transport, short sea shipping, residential and commercial heating, where direct electrification is significantly more effective. Nonetheless, the EU is advancing regulatory frameworks, developing over 40 Hydrogen Valley Projects, and establishing international import corridors to support market growth. This paper examines REPowerEU's hydrogen ambitions, balancing its potential as a key decarbonization tool against economic, technical, and logistical challenges that may hinder its realization.*

***Keywords**: GREEN HYDROGEN, BLUE HYDROGEN, HYDROGEN FOR TRANSPORT, HYDROGEN VALLEY PROJECTS, REPowerEU, DECARBONIZATION, ELECTROLYSIS.*

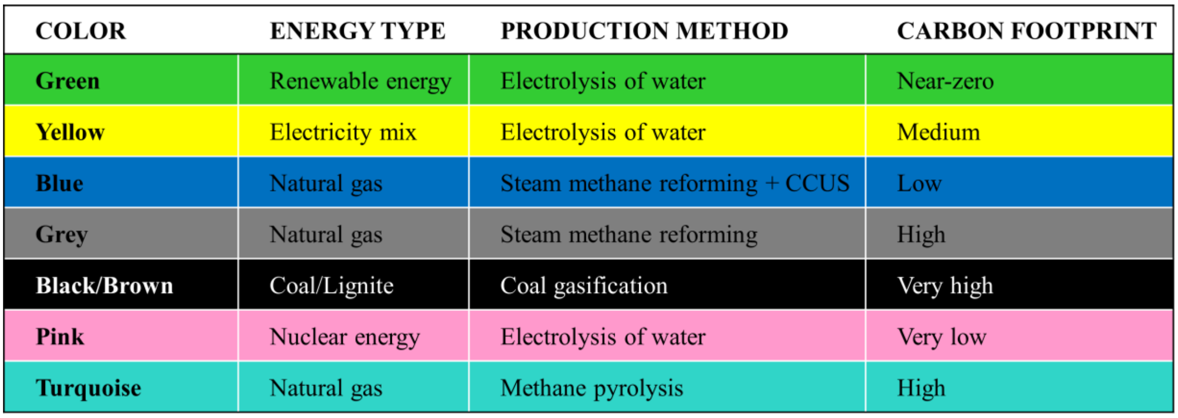
1. Introduction

In the European Union, green hydrogen is emerging as an alternative fuel for the decarbonization strategy but also as a source of debate regarding technical, economic and logistical challenges. The REPowerEU plan, launched in response to the energy crisis triggered by the Russo-Ukrainian War, has placed green hydrogen at the center of Europe's ambitions to eliminate fossil fuels and accelerate the green transition [1]. The REPowerEU plan aims to develop a green hydrogen economy, with 10 million tonnes of hydrogen produced in the EU and an additional 10 million tonnes of hydrogen imports. Beside green hydrogen, the REPowerEU plan aims to expand biomethane production from 5 to 35 billion cubic meters, wind power from 225 GW to 425 GW, solar PV from 263 GW to 750 GW, battery energy storage from 36 GWh to 260 GWh, all by 2030.

Concerning green hydrogen production, the EU will need to scale electrolysis from the current capacity of 0.3 GW to 120 GW by 2030. This represents a growth rate that exceeds even the most optimistic deployment rates of wind and solar PV during the past decade. Current installed electrolysis capacity across the entire European Union stands at 400 MW. The economic dimension of the green hydrogen economy is equally ambitious. Current production costs of green hydrogen range from 100 to 200 €/MWh, that is several times more expensive than natural gas, which typically costs between 20 and 40 €/MWh. Even blue hydrogen, produced by natural gas reforming combined with carbon capture, utilization and storage (CCUS), represents a more viable alternative with costs between 50 and 100 €/MWh. To bridge the cost gap between fossil fuels and hydrogen, the EU has established a Hydrogen Bank with an initial funding capital of €3 billion, meant to stimulate the hydrogen market.

The REPowerEU hydrogen targets have drawn criticism from economists and industry experts who question the feasibility of such rapid scaling [2]. Clean hydrogen, which includes green and blue hydrogen production, represents less than 1% of total hydrogen production in the EU. The REPowerEU goal of 20 million tonnes of clean hydrogen by 2030 represents 20% of current global hydrogen production, which stood at around 100 million tonnes in 2024 but was almost entirely produced from carbon-intensive production methods and feedstocks. The domestic production component (10 million tonnes per year) would require the EU to become the world's largest producer of clean hydrogen within just six years.

Nowadays, more than 90% of the hydrogen in the EU originates from the carbon-intensive natural gas reforming, known as grey hydrogen production. To overcome the challenges ahead, the EU is developing more than 40 Hydrogen Valley Projects across Europe. The main goal of the hydrogen valley projects is to lay the groundwork for a hydrogen economy by creating regional hubs that produce and distribute green hydrogen to the industry, transport and buildings. Ultimately, the hydrogen valleys projects should lead the way towards decarbonization of the EU industry and achieve climate neutrality by mid-century. Figure 1 summarizes the main colours of hydrogen, showing their energy type, carbon footprint, and production method.



COLOR	ENERGY TYPE	PRODUCTION METHOD	CARBON FOOTPRINT
Green	Renewable energy	Electrolysis of water	Near-zero
Yellow	Electricity mix	Electrolysis of water	Medium
Blue	Natural gas	Steam methane reforming + CCUS	Low
Grey	Natural gas	Steam methane reforming	High
Black/Brown	Coal/Lignite	Coal gasification	Very high
Pink	Nuclear energy	Electrolysis of water	Very low
Turquoise	Natural gas	Methane pyrolysis	High

***Fig. 1.** The colours of hydrogen showing their energy type, carbon footprint, and production methods*

2. Hydrogen realities and expectations in the EU

2.1. REPowerEU hydrogen targets

The REPowerEU plan sets highly ambitious hydrogen goals by 2030: 10 million tons of domestic green hydrogen and 10 million tonnes of hydrogen imports. These objectives are not realistic given current limitations in renewable energy generation, infrastructure, and resources. Compared to previous policies, the REPowerEU represents a substantial increase. The “Fit for 55” package from 2021 was targeting 5 million tonnes of green hydrogen per year, aiming to reduce greenhouse gases emissions by 55% till the end of 203. Figure 2 shown the outline of the REPowerEU strategy.

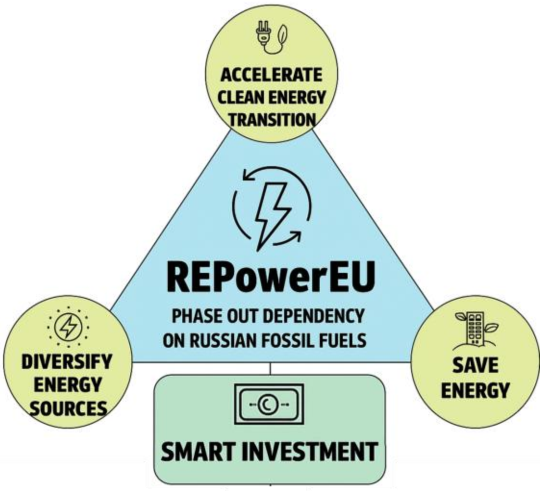


Fig. 2. *The outline of the REPowerEU plan*

Currently, annual hydrogen consumption in the EU stands at 8.3 million tonnes. More than 50% of the hydrogen demand comes from refineries, while 30% is used in ammonia and fertilizer production. The remaining hydrogen is consumed in methanol production and other chemical applications. Almost all of the hydrogen is produced by steam methane reforming (SMR). The SMR process is carbon-intensive and emits 9 kg_{CO_2}/kg_{H2}. More than 50% of the EU hydrogen consumption is concentrated in Germany, in the Netherlands, Poland, and Spain. Hydrogen production is typically located near consumption sites because pipeline transport is still underdeveloped.

The REPowerEU foresees that hydrogen consumption will increase from the present 8.3 to 20 million tonnes by 2030. It also assumes exclusive reliance on green hydrogen, although some EU member states are preferring blue hydrogen instead. Ammonia production is projected to require 3.2 Mt of green hydrogen. Oil refineries are expected to consume 2.3 Mt of hydrogen in 2030, a reduction from 4.3 Mt today due to reducing demand for gasoline and diesel as road transport electrifies. The steel industry would require 1.5 Mt, assuming that 30% of steel production will be decarbonized using hydrogen by 2030 [3]. Hydrogen for transport, including synthetic fuels (1.8 Mt) and direct hydrogen use (2.3 Mt), would require a combined 4.1 Mt. Industrial heat would require 3.6 Mt. The plan also includes 1.3 Mt for blending hydrogen with natural gas in existing gas pipelines. Additionally, the plan includes 4 Mt of imported hydrogen using ammonia as a hydrogen carrier. This corresponds to 23.5 Mt of imported ammonia (4/0.17 = 23.5 Mt), as 1 kg of ammonia contains 0.17 kg of hydrogen.

In total, the 8.8 Mt of hydrogen consumption for ammonia production (3.2 Mt), steel manufacturing (1.5 Mt), synthetic fuels (1.8 Mt), and refineries (2.3 Mt) corresponds to the present-day hydrogen consumption. However, the additional 7.2 Mt of hydrogen consumption for industrial heat (3.6 Mt), transport (2.3 Mt), and blending with natural gas (1.3 Mt) could be more efficiently decarbonized through electrification. This raises questions about the need for allocating such a large hydrogen expansion within the REPowerEU framework.

2.2. Resources need

Producing 10 Mt of green hydrogen would require enormous quantities of water and electricity from renewable power plants for powering water electrolysers. Commercial electrolysis uses 53 kWh of electricity to produce 1 kg of H_2, which contains 39.4 kWh of energy (higher heating value). This means that 10 Mt of green hydrogen would require 530 TWh of renewable electricity annually. For comparison, the annual electricity production in the EU has been around 2,800 TWh in recent years while the combined output from solar PV and wind energy was 720 TWh in 2024.

Producing 1 kg of hydrogen from water electrolysis requires 9 kg of water as a theoretical minimum. This quantity of water is defined by the chemistry of water splitting (18 kg H_2O → 2 kg H_2 + 16 kg O). In practical systems, 10–15 liters of water per kg H_2 may be required depending on technology and plant design due to water purification, cooling, and system losses. The REPowerEU target of 20 Mt of hydrogen would thus need 200-300 Mt of water just for running water electrolysers. This amount of water is about one-thousandth of the annual water consumption in the EU (hydro power included), which is approximately 200,000 Mt.

The REPowerEU anticipates a substantial growth in renewable energy capacities, targeting of 750 GW of solar PV and 425 GW of wind power by 2030. This capacity would generate a combined 1900 TWh of renewable electricity by 2030, including 830 TWh from solar PV and 1070 TWh from wind turbines. Water electrolysis equivalent to 10 Mt of hydrogen would consume 30% of the annual solar/wind electricity output, thus reducing the electricity available for direct electrification, which is more efficient in sectors such as heating and road transport [4]. If electricity is converted into hydrogen via electrolysis (60% efficiency), then compressed, stored, and used in fuel cells (50% efficiency), the end-to-end efficiency drops to 30%. By comparison, electrification for transport is 75% efficient (battery-to-wheel efficiency) and 100% or more for heat pump heating.

Overreliance on hydrogen could also increase social resistance due to higher energy costs and space requirements for the hydrogen infrastructure. Hydrogen imports would require strict certification and traceability to ensure that the hydrogen delivered to the EU is truly green and not produced from carbon-intensive electricity and processes.

2.3. Technical challenges

Electrolyser capacity presents another challenge. REPowerEU foresees 120 GW of electrolysers powered by renewable energy by 2030. This level of deployment is highly uncertain, given the limitations of supply chain and raw materials. The European Court of Auditors [5] has concluded that green hydrogen projects in advanced stages across the EU could produce between 2.5 and 4.4 million tonnes by 2030, several times short of the REPowerEU target of 20 million tonnes. On the first hand, the EU high hydrogen targets aim to create overcapacity and secure market competitivity, while on the second hand, this strategy carries economic and environmental risks, given current constraints on renewable energy, infrastructure, and raw materials.

Currently, electrolyser manufacturing represents a technical bottleneck. Current global manufacturing capacity stands at 25 GW per year, with China accounting for 60% of the global production. Meeting EU targets would require electrolyser manufacturing capacities to increase to 100-150 GW, while resolving supply chain constraints for critical raw materials including platinum, iridium, and membrane components. Current global production of iridium and platinum could support only 10 GW of annual PEM electrolyser manufacturing, compared to 100-150 GW of targeted capacities.

Failure to deliver sufficient electrolyser capacity could increase the production of grey hydrogen, undermining emissions reductions and climate goals. The environmental benefits of green hydrogen depend on the carbon intensity of the electricity used for water electrolysis. Producing hydrogen using renewable energy has negligible carbon footprint, however, in case of renewable energy scarcity, grid electricity would be used instead. In the EU-27, the average carbon intensity of the grid mix was 210 grams of CO_2 per kWh of electricity in 2023. Thus, using grid electricity would result in the emissions of 11 kilograms of CO_2 per kilogram of hydrogen, assuming an average electricity need of 53 kWh per kilogram of hydrogen for commercial electrolysis.

Hydrogen leakage during production, storage, and transport has been shown to have a global warming potential (GWP) of 10-12 kg_{CO2}/kg_{H2} over 100 years. Hydrogen (H_2) is not a greenhouse gas in the traditional sense, it does not directly trap heat in the atmosphere by absorbing infrared radiation, like CO_2, CH_4 or N_2O. However, H_2 acts as an indirect greenhouse gas: when released into the atmosphere, it reacts with other chemicals, especially by consuming hydroxyl radicals (OH). Recent research found that the hydrogen stratospheric chemistry increases the lifetime of methane (CH_4) and leads to higher levels of ozone (O_3) and water vapor (H_2O) in the stratosphere, all of which are greenhouse gases.

There is significant geographical mismatch between hydrogen production sites (North Sea, Southern Europe) and industry-heavy regions when the hydrogen will be consumed (Central Europe). Therefore, building a hydrogen economy in the EU will necessitate a coordinated development of transport and storage facilities. The European Hydrogen Backbone program envisions 50,000 km of pipelines by 2040 [6], but progress is behind schedule. Only the construction of one hydrogen pipeline is currently underway, while most projects are still at the feasibility study stage.

Hydrogen transport via pipelines costs between 0.3 and 0.5 €/kg per 1,000 km. The hydrogen pipeline and transport infrastructure will be a multi-billion € investment. Cost estimates range between 30 and 40 billion € for pipelines and between 5 and 10 billion € for storage. Hydrogen properties (low energy density, high propensity for leakage, embrittlement risks in metals) makes the conversion of existing natural gas pipelines into hydrogen pipelines challenging. About 50% of natural gas pipelines are expected to be retrofitted for hydrogen while the rest needs entirely new construction.

Transporting hydrogen, either as compressed (CH_2) and liquid (LH_2) hydrogen or in carriers such as ammonia and methanol, introduces specific space requirements, auxiliary systems, materials and safety regulations [7]. The energy density of hydrogen gas at the atmospheric state (1 Atm, 15 °C) is very low, only 0.01 MJ/L, based on lower heating value (LHV) of 120 MJ/kg. The energy density increases for compressed hydrogen (CH_2), and is equal to 4.4 MJ/L at 600 Atm. Liquid hydrogen (LH_2) achieves twice the energy density of compressed hydrogen. At cryogenic temperature (-253 °C) the energy density of hydrogen is 8.7 MJ/L.

Hydrogen can be stored in liquid ammonia (NH_3). Ammonia liquefies at -33.4 °C at atmospheric pressure. Alternatively, at room temperature, ammonia liquefies at pressures above 8.5 Atm. The mass density of liquid ammonia at 20 °C and 8.5 Atm is 610 kg/m^3 and the energy density is 11.4 MJ/L, based on LHV of 18.6 MJ/kg. The mass fraction of hydrogen in ammonia is 17.6%, meaning that the mass density of hydrogen in ammonia is $0.176 \times 610 = 108$ kg/m^3. The energy density of hydrogen in liquid ammonia is then 0.108 kg/L $\times$ 120 MJ/kg = 12.9 MJ/L, which is higher than the energy density of LH_2 (8.7 MJ/L). Methanol (CH_3OH) is another potential hydrogen carrier, with an LHV of 19.9 MJ/kg and liquid density of 791 kg/m^3 at the atmospheric state. The energy density of methanol is then $0.791 \times 19.9 = 15.7$ MJ/L. The mass fraction of hydrogen in methanol is 12.5%, which returns an energy density of hydrogen in liquid methanol is equal to $0.125 \times 120 = 15$ MJ/L, the highest volumetric energy density among the observed storage modes. Figure 3 compares the gravimetric (MJ/kg) and volumetric (MJ/L) energy densities of hydrogen with other fuels.

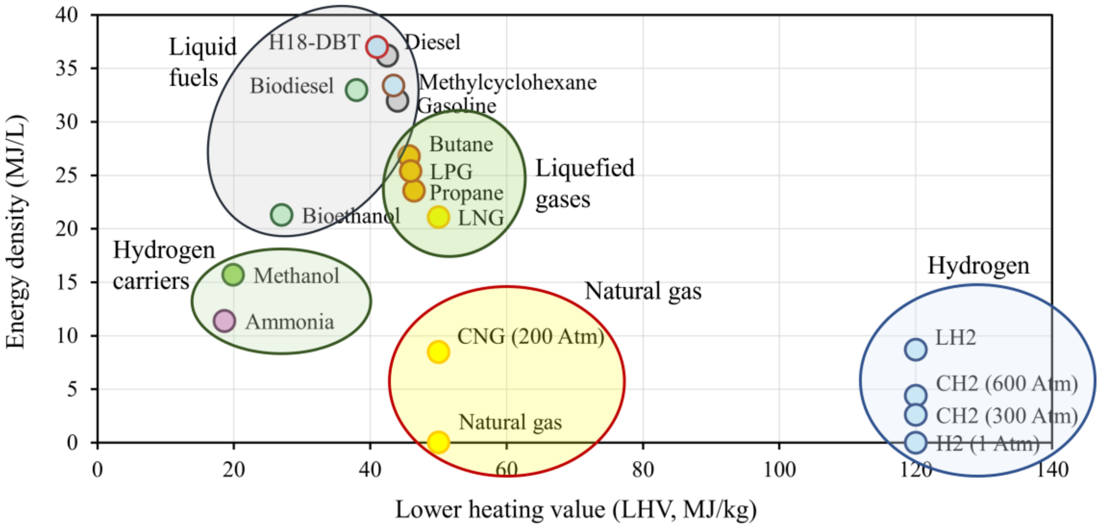


Fig. 2. *Gravimetric (MJ/kg) and volumetric (MJ/L) energy density of hydrogen and other fuels*

Liquid Organic Hydrogen Carriers (LOHCs) are organic compounds that reversibly absorb and release hydrogen through hydrogenation and dehydrogenation reactions. Examples include toluene (C_7H_8) hydrogenated to methylcyclohexane (C_7H_{14}) and dibenzyltoluene ($C_{21}H_{20}$) hydrogenated to perhydro-dibenzyltoluene ($C_{21}H_{38}$, H18-DBT). These liquid compounds store hydrogen at mass fractions between 5.5 and 7.5%. The process involves hydrogenating an unsaturated carrier to yield a saturated form, which can then be dehydrogenated to release pure hydrogen when needed. The hydrogen content in fully hydrogenated LOHCs achieve energy densities in the range of 6.5-9.0 MJ/L, comparable to LH_2, but without the need for cryo-temperatures. LOHCs also have heating values of around 40 MJ/kg if burned directly, similar to traditional liquid fuels such as gasoline and diesel. These compounds store hydrogen in the liquid form at room temperatures and could benefit from existing fuel transport and storage infrastructure. On the downside, the efficiency of LOHCs is limited by the energy needs for hydrogenation and dehydrogenation.

Ammonia, methanol and LOHCs are seen as alternatives to the direct use of hydrogen for future transportation. Green hydrogen from water electrolysis is used as feedstock for the production of ammonia, methanol and LOHCs. Ammonia can be used in internal combustion engines or solid oxide fuel cells, offering zero CO_2 emissions, but NO_x emissions require treatment. It has lower energy density than heavy fuel oil, so ships need larger tanks, and its high toxicity poses serious risks to crew and port safety. Ammonia production is well established in the chemical industry and its use in maritime transport could benefit from the existing storage and transport infrastructure. Methanol can run modified diesel engines with some retrofits, produces lower NO_x and particulate emissions than marine diesel. It has half the volumetric energy density of heavy fuel oil, and needs larger tanks and more frequent refuelling. LOHCs are compatible with existing liquid fuel handling systems. However, they need complex onboard dehydrogenation systems before use in fuel cells or hydrogen engines, and introduce efficiency penalties. Compared to ammonia and methanol, LOHCs need even larger tanks due to lower energy densities of the hydrogen content. LOHCs infrastructure for large-scale maritime use is not yet developed.

2.4. Economic challenges

The EU's hydrogen ambitions hide a fundamental disadvantage: renewable hydrogen is between three and ten times more expensive than conventional energy alternatives. Green hydrogen costs are between 100 and 200 €/MWh, blue hydrogen costs are 50-100 €/MWh while natural gas costs are only 20-40 €/MWh.

The levelized cost of hydrogen (LCOH) is affected by two primary factors: electricity costs and electrolyser costs. Electricity accounts for 60-70% of the LCOH while electrolyser costs account for the remaining 30-40% [8]. The LCOH of green hydrogen is 3.5-7.0 €/kg, which translates to roughly 100-200 €/MWh, taking a lower heating value (LHV) of hydrogen of 120 MJ/kg or 33.3 kWh/kg. REPowerEU targets for the LCOH are around 1.5-3 €/kg, that is 40-90 €/MWh by 2030. An increase of 10 €/MWh in the price of electricity would add 0.5 €/kg to the LCOH. Alkaline electrolysers costs are between 700 and 1300 €/kW, while the costs of proton exchange membrane (PEM) electrolysers are even higher, between 1400 and 2000 €/kW. Low-cost renewable electricity from wind and solar PV powering highly efficient electrolysers are expected to drive the LCOH decline in the future. Projections suggest that the costs of electrolysers must decline by 70-90% from current levels, to 200-500 €/kW by 2030 to enable hydrogen competitiveness.

Blue hydrogen, produced by steam methane reforming with CCUS, presents a more economical solution in the near term with costs between 2.0-3.5 €/kg, which translates into 60–105 €/MWh. The cost of blue hydrogen is highly sensitive of natural gas prices and carbon pricing. Blue hydrogen becomes more competitive to than other fuel types at carbon prices above 100 €/t_{CO2}, which is expected to occur in the future. In 2024, however, the average price of CO_2 within the EU ETS was 65 €/t_{CO2}, with annual fluctuations in the range of 50-75 €/t_{CO2}.

The costs of steelmaking increase considerably when using green hydrogen instead of fossil-derived hydrogen or traditional reductants such as coal or natural gas. In steel production, the use of green hydrogen for hydrogen-based direct reduced iron (H_2-DRI route) increases the costs by 100–200 €/t of steel compared to conventional natural gas-based DRI routes. These cost increase represent a 15-30% increase over the costs of conventional steel. The average cost for steel in Europe is 600 €/t for construction and industrial steel grade. The cost impact on final products using green steel is much smaller. For instance, using green hydrogen for steel production would add about €200 to a passenger car or €1000 to a residential unit of 100 m^2, generally less than a 1% increase over the original price of the product.

The cost of ammonia produced using green hydrogen (green ammonia) is higher than ammonia produced with natural gas (grey ammonia) or with carbon capture (blue ammonia). Green ammonia production costs typically range between 700 and 1000 €/t in 2025, compared to blue ammonia (with carbon capture) at around 400-600 €/t while conventional (grey) ammonia costs are 200-300 €/t. Although green ammonia costs 2-3 times more than grey ammonia, the impact on food prices through fertilizer use is typically small due to the fertilizer's small share in total agricultural costs.

Switching air and maritime transport from traditional fossil fuels to hydrogen, ammonia or synthetic fuels would increase transport costs. Production cost for synthetic kerosene for aviation varies between 3,500 to 5,500 €/t while the production cost of renewable hydrogen for aviation is between 5,000 and 8,000 €/t. For comparison, conventional jet fuel averaged 700 €/t in Europe in 2024. Estimates suggest that airfares would increase by 50% if synthetic fuels replaced fossil kerosene by 2050. Operating costs for hydrogen aircrafts are expected to be even higher. Estimates suggest that airfares for hydrogen planes would increase by 10-20% for short-range flights up to 40-50% for long-range hauls.

Maritime transport using hydrogen in the form of ammonia, methanol and LOHCs is more expensive than traditional maritime transport with heavy fuel oil (HFO), marine diesel oil (MDO), or LNG. Higher transport costs reflect the higher costs of fuel production, larger onboard tank, plus the costs for research and development of engines and onboard systems managing the green fuels. Green ammonia (700-1000 €/t) is currently from 2 to 3 times more expensive than marine heavy fuel oil (400-500 €/t). In the short term, ammonia- LNG dual-fuel ships may be the most cost-effective pathway, with ammonia becoming more competitive after 2040 as the technology matures. Green methanol is even more expensive with prices between 1000 and 2000 €/t. Estimates for the cost increase for ships ammonia and methanol range between 50% and 300%, especially for long-haul sea transport.

3. Conclusions

Europe's path to a hydrogen economy by 2050 will be defined by its ability to reconcile ambitions with realities. The REPowerEU vision identifies hydrogen as a fuel for decarbonization of hard-to-abate sectors such as power generation, the production of steel, ammonia and cement, and long-distance air and maritime transport. Nowadays, green hydrogen competes not only with fossil fuels but also with direct electrification alternatives. The challenges laid out are profound and hydrogen could become a costly mistake without careful planning, especially in sectors where direct electrification is easier and more efficient. By 2050, Europe will need to fully integrate hydrogen production, storage, and transport across the entire continent. Hydrogen costs must be cut down by a lot through economies of scale, technological innovation and the deployment of low-cost renewable electricity. Hydrogen deployment must be strategic, focused on sectors where no viable alternatives exist and avoid its use in sectors where other energy sources are cheaper and more efficient. The REPowerEU strategy is a high-risk gamble that could either turn out to be an expensive failed investment or the cornerstone of a climate-neutral and economically resilient Europe.

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