Hydrogen Europe

Long-term outlook on zero-emission mobility

Results from HE mobility survey

DISCLAIMER

Data and analysis provided within this report are the results of a survey conducted with the membership of Hydrogen Europe. Therefore, it reflects the views, suggestions, and projections of different types of stakeholders connected to in some form to the hydrogen economy (industry, SMEs, national associations, etc.).

Some of the results show the projections of different vehicle types in the following years up to 2050. It should be noted that these are market projections that may significantly differ from the eventual outcomes, as the projections are highly dependent on market parameters, not only related to mobility, but also to the global market.

Contents

List of figures

List of tables

Executive summary

The transport sector is a significant contributor to European and global greenhouse gas emissions, making it imperative to address CO_2 and greenhouse gases (GHG) emissions from all modes of transport. This survey highlights Hydrogen Europe members' expectations on key available technologies and the possible role of different zero-emission solutions, particularly on clean hydrogen solutions, in reducing emissions from the transport sector.

THE URGENT NEED FOR EMISSION REDUCTION:

- The transport sector in Europe, covering road, air, and maritime transport, is responsible for a quarter of the bloc's GHG emissions. Reducing emissions from transport is crucial to combatting climate change and achieving EU sustainability goals and climate goals.

ZERO-EMISSION TECHNOLOGIES:

- Hydrogen technologies: Fuel Cell Electric Vehicles (FCEVs) use hydrogen to produce electricity, emitting only water vapor, making them a promising alternative for zero-emission road transport. Additionally, manufacturers are taking an interest in hydrogen internal combustion engines (H2 ICE) as an additional solution.

- With most of the legislative framework on the emissions from road vehicles, ships and airplanes set, we can expect fast progress in the development of zero-emission alternative fueled propulsion systems, based on direct use of hydrogen or hydrogen derivatives.

APPLICATION ACROSS TRANSPORT MODES:

- Road Transport: BEV, FCEV and H2 ICE have made significant progress – BEV dominates the passenger cars segment, while hydrogen has significant potential to decarbonise heavy-duty road transport (buses and trucks). H2 ICE is showing potential in long distance travel, particularly for reducing GHG emissions in trucking.

- Aviation: Developing aircrafts using hydrogen-based fuels and exploring synthetic fuels and SAFs can reduce emissions in aviation across the different segments of the sector.

- Maritime: Hydrogen fuel cells and different hydrogen-based systems show promise for emissions reduction in maritime transportation. Even though the technology is still on the rise and other alternative fuels are momentarily dominant (e.g. e-fuels and biofuels), hydrogen-powered vessels show much promise.

INFRASTRUCTURE DEVELOPMENT:

- Building a dense and user-friendly refuelling infrastructure is crucial for the widespread adoption of hydrogen technologies.

- Governments and private sector stakeholders must invest in the deployment and use of infrastructure for alternative fuels to support clean transport solutions.

POLICY AND REGULATORY SUPPORT:

- Governments worldwide are implementing policies such as emissions standards, infrastructure deployment, tax incentives, emissions trading schemes, and climate legislations to encourage the adoption of clean transport technologies.

CHALLENGES AND CONSIDERATIONS:

- Cost: The initial cost of zero-emission technologies can be higher, but long-term operational savings and reduced emissions justify the investment.

- Infrastructure: Expanding infrastructure for hydrogen refuelling is a significant challenge that requires coordinated efforts.

- Energy pricing: The final energy/fuel price for the user at the refuelling station will be of paramount importance to the sustainability of the HRS business model and uptake of hydrogen vehicles in corporate fleets.

- Supportive environment: EU members states need to support the offtake of zero-emission transport through levelling the playing fields and balancing out the total cost of ownership (TCO) with the changes in energy taxation directive (ETD), pricing of carbon emissions (ETS in road transport), State Aid support for deployment of rolling stock and infrastructure and similar.

CONCLUSION:

- Transitioning to zero-emission technologies and clean hydrogen solutions is a critical step in reducing emissions from all transport modes.

- Collaboration between governments, industries and consumers is essential to accelerate the adoption of these technologies and achieve a sustainable, low-carbon transport future.

Addressing emissions from all transport modes through the deployment of zero-emission technologies and clean hydrogen solutions is a multifaceted effort that holds promise in mitigating climate change and promoting a more sustainable and environmentally friendly transport sector, but at the same time fosters sustainable development, new jobs and business opportunities. It requires a collaborative approach involving governments, industries, R&I and individuals to successfully reduce emissions and transition to a cleaner and more sustainable future.

Introduction

As transport remains a highly polluting sector for which emissions continue to increase every year, hydrogen solutions (including hydrogen derivatives as fuels) can help to achieve the EU goal of 90% reduction of CO2 emissions for all transport modes by 2050. Many segments of the mobility sector are suitable for consumption of the large quantities of produced or imported hydrogen foreseen by the EU through its various strategies, contributing to their decarbonisation.

However, the projections on the deployment of hydrogen vehicles, vessels, and aircraft heavily depends on the industry players and manufacturers, which determine the size of the hydrogen mobility market in the near (and far) future. Most of this data is confidential and cannot be presented in public studies and analysis, leaving projections to different consultancies and organisations, which procure them with various assumptions. As these assumptions might significantly differ from one another, it leads to significant knowledge gaps.

Therefore, this analysis is based on the responses of members of Hydrogen Europe (HE), through implementation of an anonymous survey – where relevant stakeholders' data is protected but can still be shared.

The questions covered the whole mobility sector – road, maritime, aviation and refuelling stations. Analysis of the data shows an expected steady increase in number of hydrogen-powered applications across all mobility and transport modes, as well as the issues and bottlenecks the members find most relevant and in need of urgent solutions for the faster uptake of hydrogen mobility.

THE RESULTS WILL BE USED FOR SEVERAL PURPOSES:

Providing projections development; aligning internal and external communications; enabling more comprehensive inputs to the European Commission; preparation of Hydrogen Europe position papers; quicker response to members' requests for support; improved long-term communication with media.

The following chapters present the approach and methodology of the survey, as well as the results in each specific segment.

Road transport

Road transport is one of the key pillars of economic growth, and its transfer to zero-emission solutions is imminent. Therefore, the number of alternative fuels vehicles, including hydrogen-powered, is going to increase tenfold by 2050[1]. With the implementation of goals set by Alternative Fuels Infrastructure Regulation (AFIR)[2], the number of HRS will increase, enabling the uptake of road vehicles. These include trucks, buses, cars and vans.

The number of manufacturers working on deploying their hydrogen-powered models is growing each day, broadening the choice for end-users. However, their market plans are informed by market demand, which is unknown. Therefore, the following projections might prove helpful to the manufacturers, as well as end-users, to see what the penetration of hydrogen-powered vehicles (both fuel cells and hydrogen internal combustion engines) is expected to be in the future.

Additionally, besides the projections of observed vehicles on the road, bottlenecks and issues occurring during the uptake and deployment of the aforementioned are also considered. The respondents provided their views on the importance of specific bottlenecks, in terms of technical, legislative and market challenges that occur.

As the respondents' scope of organisation and activities is various, the results obtained through the survey also differ. To objectify the obtained results, a Median function in Excel was used, considering also the 25th and 75th percentile. This means that the results show the middle value in a set of responses, rather than average, which might significantly differ from the realistic case. The percentiles are also presented to show the lower and upper results within the provided responses. Moreover, for each segment, a set of assumptions was determined and presented in the footnotes, to unify the obtained results.

Trucks

The first question related to the heavy-duty vehicles in the road sector was the following: **"What will be the penetration of H_2-powered trucks (both FCEV and H_2 ICE) in Europe in 2025-2040?".** The results are presented in percentages for each observed year (5-year interval).

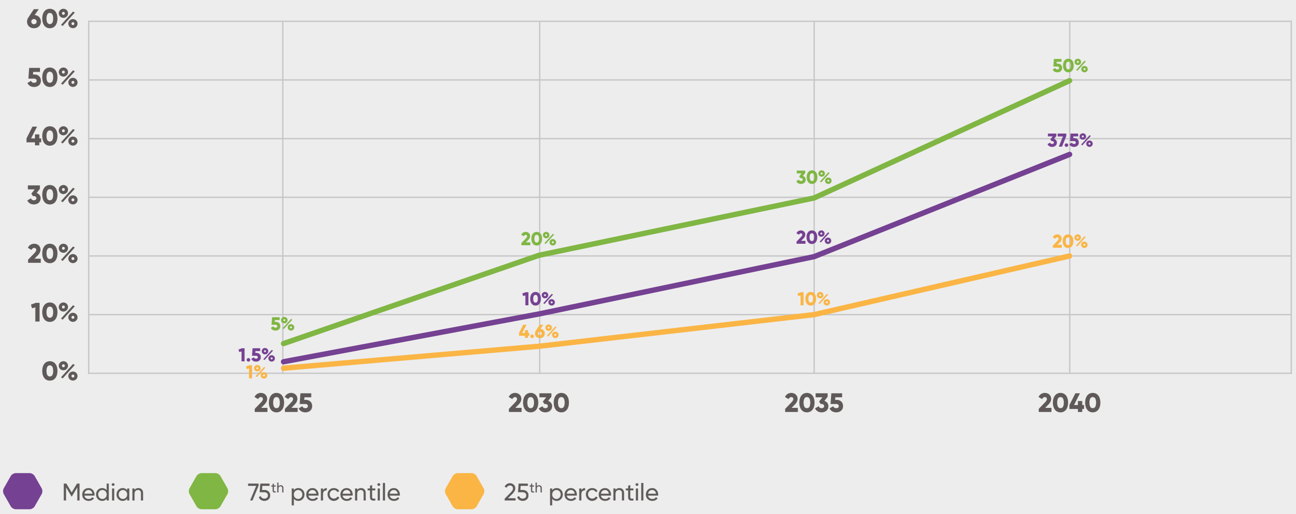
The results of the responses analysis are presented in **Figure 4**, based on the following assumptions:

- Data presents the penetration of new vehicles in the observed year.
- Responses presented in number of trucks are presented as percentages, by using extrapolated data in observed year. The extrapolated data is based on ACEA current yearly database of trucks[3].
- Responses presented as ranges are averaged between the lowest and highest estimation.
- Powertrains considered in the question are fuel cell electric vehicles (FCEV) and hydrogen internal combustion engines (H_2ICE) combined.

1 / Consilium, Infographic - Fit for 55: Towards More Sustainable Transport, July 2023.
2 / European Commission, Regulation (EU) 2023/1804 of the European Parliament and of the Council of 13 September 2023 on the Deployment of Alternative Fuels Infrastructure, and Repealing Directive 2014/94/EU, September 2023
3 / ACEA, Vehicles in Use – Europe 2023, January 2023.

FIGURE 1

Penetration of H_2-powered trucks in new vehicle sales in 2025-2040



Considering long-term solutions for different truck types, they were based on vehicles determined in **Annex 1** of Commission Regulation (EU) 2017/2400[4], summarized in the following table:

TABLE 1

Explanation of the vehicle categories

NAME		LONG HAUL	REGIONAL DELIVERY	URBAN DELIVERY	MUNICIPAL UTILITY
Axle configuration	4x2	x	x	x	x
	6x2	x	x		x
	6x4	x	x		x
	8x4				
Chassis configuration	Rigid	x	x	x	x
	Tractor	x	x		
Technically permissible max. laden mass (tons)	7.5-10		x	x	
	>10-12	x	x	x	
	>12-16		x	x	
	>16	x	x		x
	All weights	x	x		x

4 / European Commission, Commission Regulation (EU) 2017/2400 of 12 December 2017 Implementing Regulation (EC) No 595/2009 of the European Parliament and of the Council as Regards the Determination of the CO2 Emissions and Fuel Consumption of Heavy-Duty Vehicles and Amending Directive 2007/46/EC of the European Parliament and of the Council and Commission Regulation (EU) No 582/2011, December 2017.

Based on this determination of the truck's types, the following results were obtained, with the full percentages presented in **Annex 2**:

FIGURE 2

Long-term solution for long-haul trucks

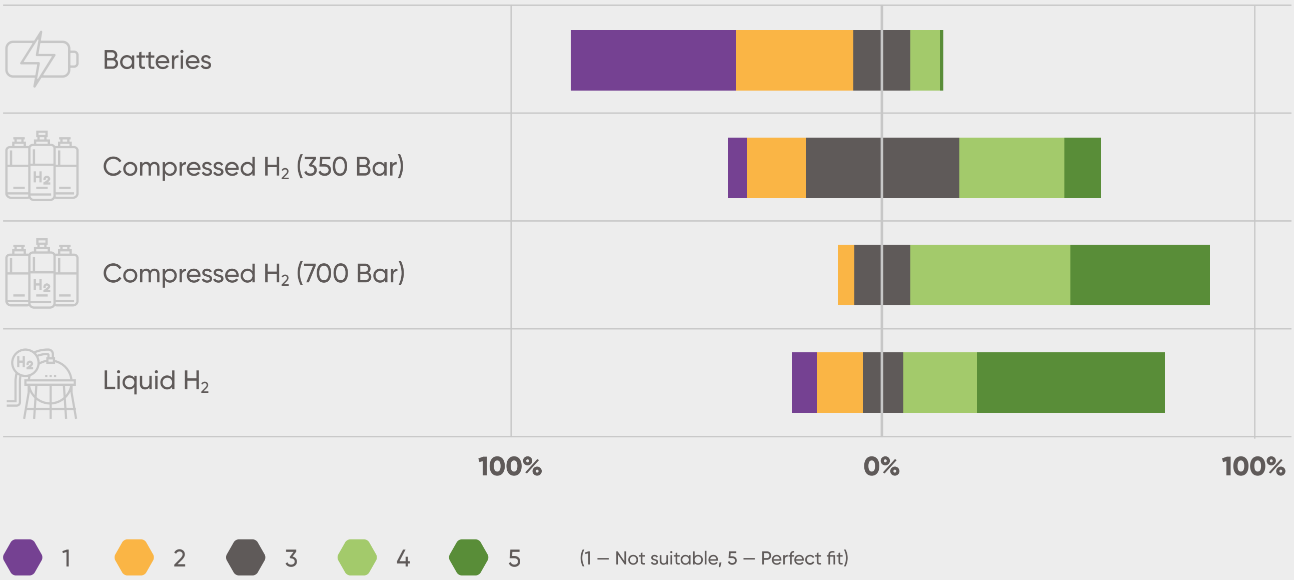


FIGURE 3

Long-term solution for regional delivery trucks

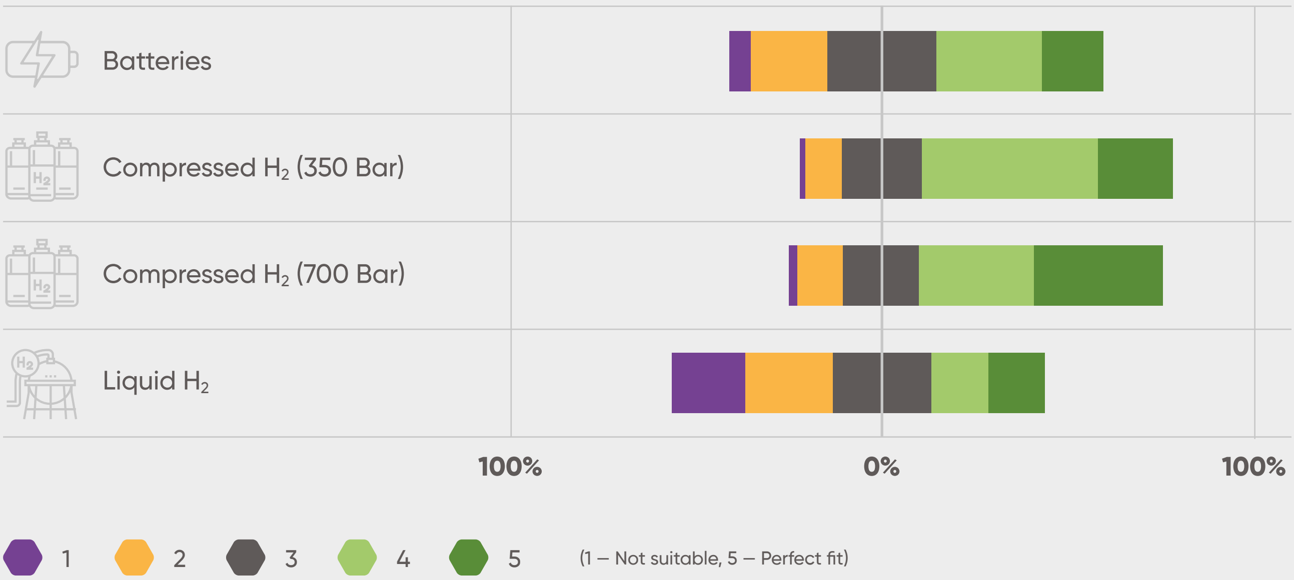


FIGURE 4

Long-term solution for urban delivery trucks

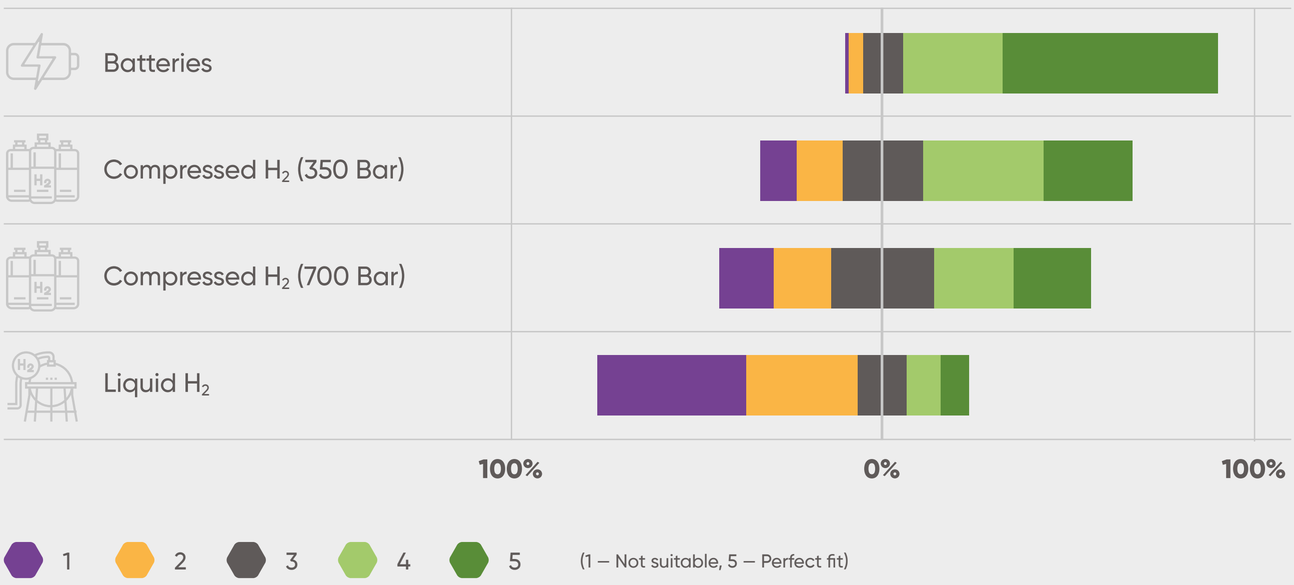
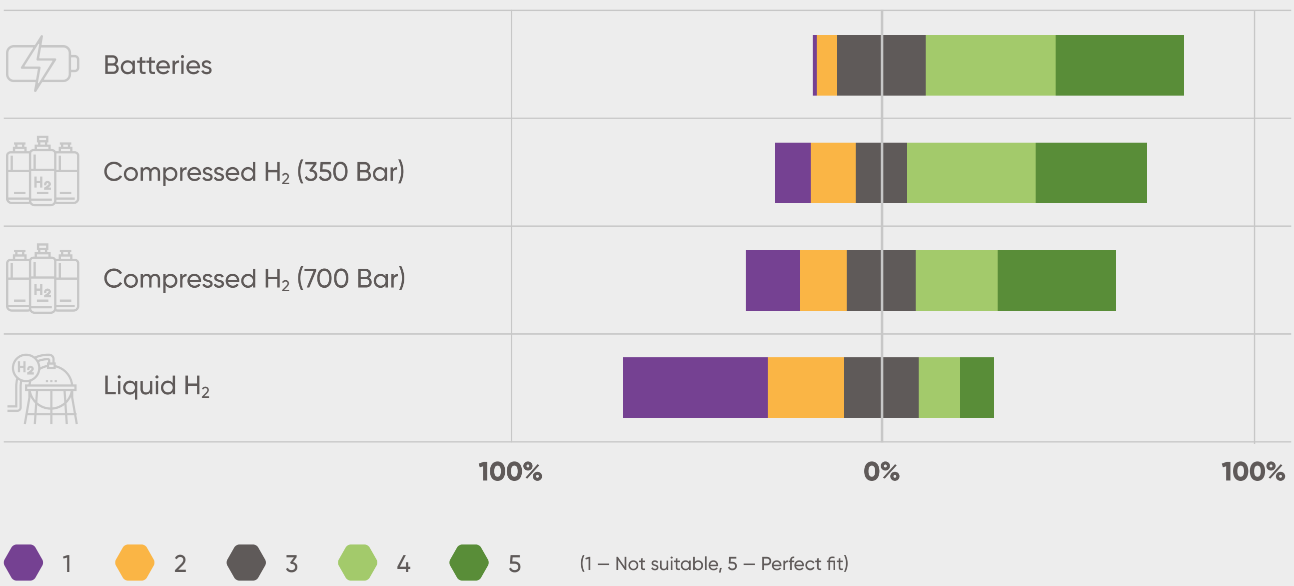


FIGURE 5

Long-term solution for municipal utility trucks



The responses show hydrogen-powered solutions are better suited to long-haul and regional applications, while for shorter distances, batteries are considered as a better solution (urban deliveries and utility trucks). Further distribution of hydrogen solutions can be done based on storage solutions – to compressed gaseous hydrogen (at 700 bar) and liquid hydrogen.

However, the choice of final solution is not that simple, as can be concluded from the figures:

- For **long-haul trucks,** compressed gaseous hydrogen (at 700 bar) and liquid hydrogen are defined as a better solution, in comparison to compressed gaseous hydrogen (at 350 bar) and especially batteries. Even though all the solutions are considered, liquid hydrogen is the closest to “perfect fit”, based on the results, and considered the future solution for this type of vehicle.

- For **regional delivery trucks**, the choice gets more complicated. Fewer respondents were able to point towards a specific option as the “perfect fit”, as different solutions could cover the segment’s needs. Highly developed batteries have proven to cover relatively high distances, while all hydrogen options seem feasible. Respondents only found liquid hydrogen as a less desirable option for this truck segment.

- In terms of **urban delivery trucks,** preferences gravitate towards batteries, as there is no need to cover long distances. Trucks can be charged in the depots during the night, and their daily capacities are enough to cover daily tasks. However, hydrogen solutions are also available and plausible – which leaves the powertrain selection to the end-user depending on their needs.

- **Municipal utility trucks** are viewed similarly to urban delivery trucks. However, the choice of solution in this case tends to move towards hydrogen powertrains, as the trucks in this segment are usually quite heavy and require more power. Additionally, they have a significant load they need to handle, not leaving much space on the truck to carry heavy batteries. Therefore, the choice of the powertrain depends mainly on the distances that need to be covered, as well as the purposes for which it will be used (garbage disposal, streets cleaning, etc.).

Furthermore, bottlenecks and issues with faster deployment of hydrogen-powered trucks were also examined, and the responses provided the results presented in **Figure 6** (while the details are presented in **Annex 3**). The figure shows three major bottlenecks that respondents believe need to be resolved as soon as possible (ranking of 5, with responses rate of over 40%):

- Lack of infrastructure (66.0%);
- High CAPEX (48.9%) and
- Lack of incentives for buyers (43.6%)

There are other bottlenecks that need to be resolved, as presented in the figure – however, the consensus determined within the scope of this survey is that there is a need for lower prices (followed by incentives for buyers), as well as for the fast deployment of infrastructure.

FIGURE 6

Bottlenecks and issues with H_2-powered trucks

Buses and Coaches

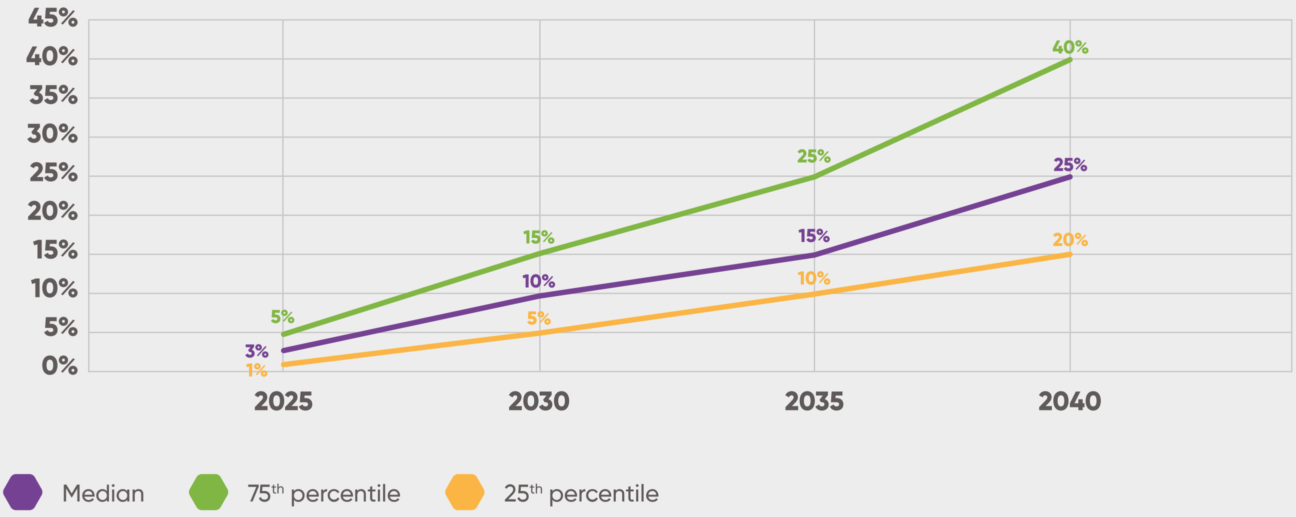
Determining the projection of buses and coaches on the market, the initial question related to the road sector was the following: **"What will be the penetration of H_2-powered buses and coaches (both FCEV and H_2 ICE) in Europe in 2025-2040?".** The results are presented in percentages for each observed year (5-year interval).

The results of the responses analysis are presented in **Figure 7**, based on the following assumptions:

- Data presents the penetration of new vehicles in the observed year.
- Responses presented in number of buses and coaches are presented as percentages, by using extrapolated data in observed year. The extrapolated data is based on ACEA current yearly database of buses and coaches.
- Responses presented as ranges are averaged between the lowest and highest estimation.
- Powertrains considered in the question are fuel cell electric vehicles (FCEV) and hydrogen internal combustion engines (H_2ICE) combined.

FIGURE 7

Penetration of H_2-powered buses and coaches in new vehicle sales in 2025-2040



Considering buses and coaches types, they were differentiated based on the distances travelled:

- Urban buses: up to 300 km;
- Intercity buses: between 300 and 500 km and
- Coaches: above 500 km.

Based on this determination of the buses and coaches types, the following results are obtained, with the full percentages presented in **Annex 4**:

FIGURE 8

Long-term solution for urban buses

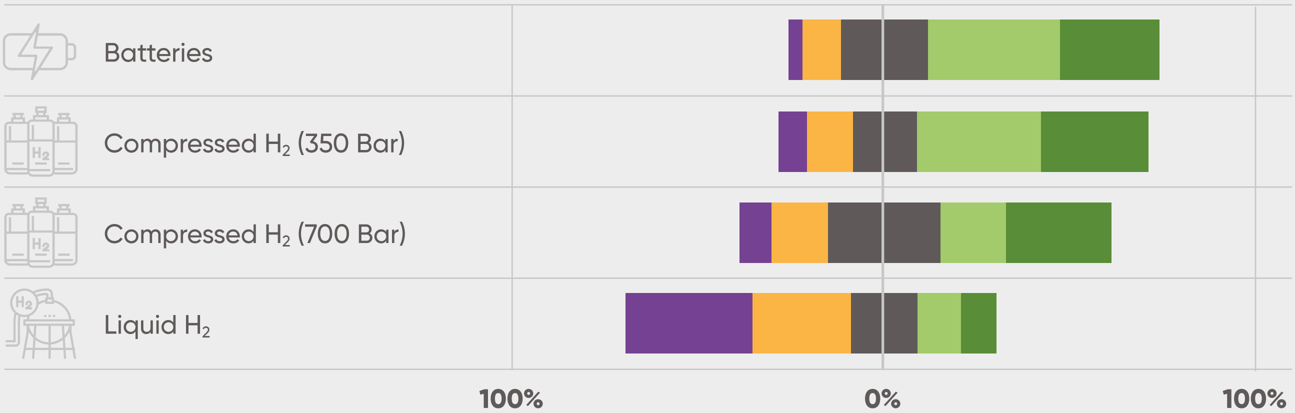


FIGURE 9

Long-term solution for intercity buses

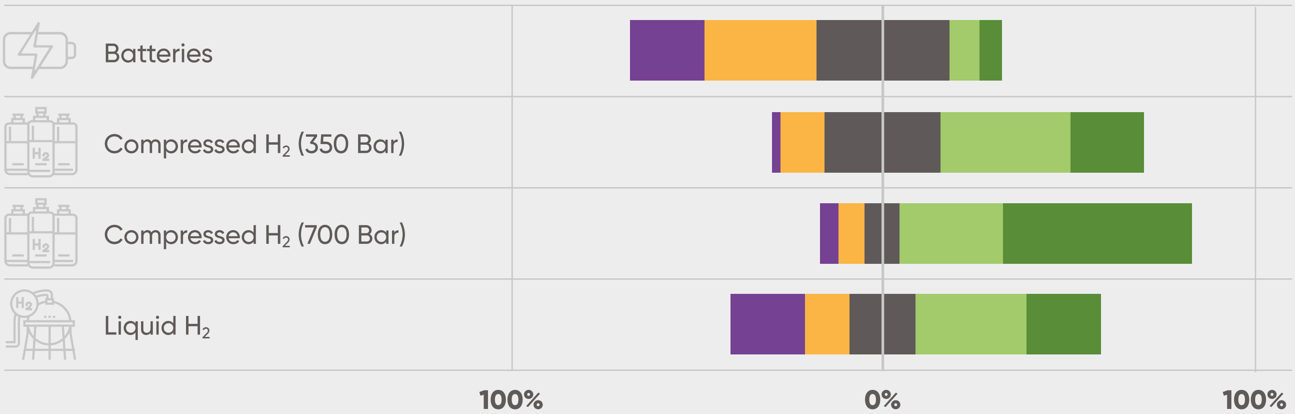
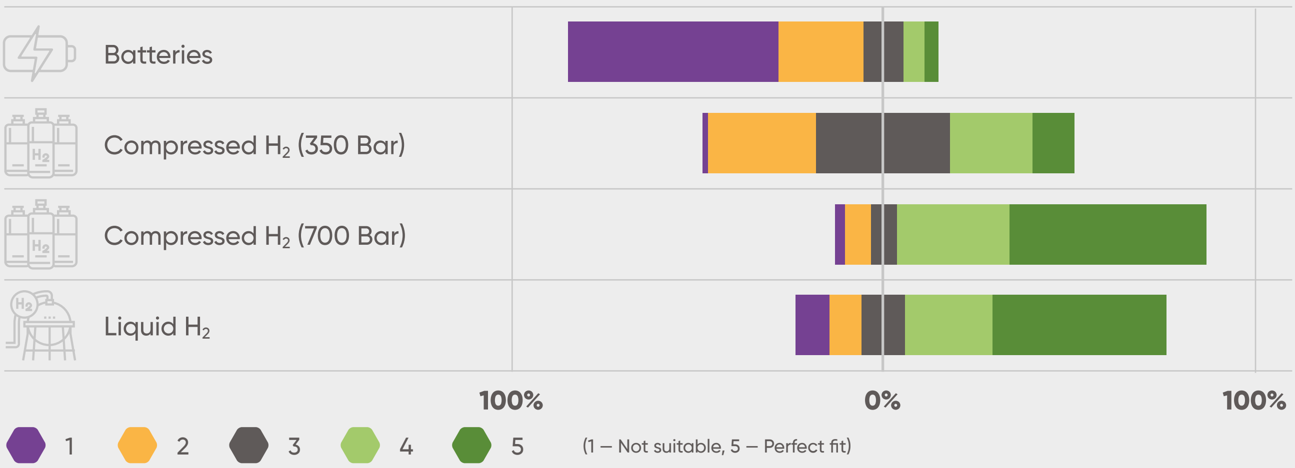


FIGURE 10

Long-term solution for coaches



From the responses, hydrogen-powered solutions are viewed as better suited to long-haul and regional applications while, for shorter distances, batteries are considered as a better solution (urban buses). However, as opposed to trucks, hydrogen solutions for buses and coaches consider all three solutions: compressed gaseous hydrogen (at 350 and 700 bar), as well as liquid hydrogen.

However, the choice of final solution is not that simple, as can be concluded from the figures:

- For **urban buses,** the competition between battery electric and hydrogen-powered buses is ever present. This can be related to many parameters and factors that need to be considered while buying an urban bus for daily purposes. The choice is mainly dependent on the elevation factor, meaning that battery-electric buses are more applicable in lowland areas, while hydrogen-powered buses show their benefits in hilly areas. It should also be noted that compressed gaseous hydrogen (at 350 bar) shows more potential in urban areas, as the buses have more room to store the additional hydrogen (that is less compressed) and require less energy for compression.

- Moving to **intercity buses,** the choice gets clearer – hydrogen-powered solutions prevail significantly, with major focus on compressed gaseous hydrogen (at 700 bar). Considering the need for more power and range, as well as the existing infrastructure framework (with a lack of liquid hydrogen stations), this is the logical solution for intercity travelling of passengers.

- In terms of **coaches,** the situation is even clearer. Hydrogen solutions provide longer ranges, with liquid hydrogen showing its benefits. However, the compressed gaseous hydrogen (at 700 bar) is still the most applicable solution, which can be connected to the previous explanation for infrastructure.

Furthermore, bottlenecks and issues with faster deployment of hydrogen-powered buses and coaches were also examined, and the responses provided the results presented in **Figure 11** (while the details are presented in Annex 5). The figure shows three major bottlenecks that respondents consider need to be resolved as soon as possible (ranking of 5, with responses rate of over 40%):

- Lack of infrastructure (57.5%);
- High CAPEX (57.5%) and
- High OPEX (47.1%)

There are, also, other bottlenecks that need to be resolved, as presented in the figure – such as a lack of incentives for buyers, which is slowing down the purchase of (still) more expensive buses and coaches than the existing diesel or LNG ones. Additionally, the lack of safety measures within the legislative framework is also slowing down faster deployment of these vehicles, which needs to be resolved soon.

However, the general consensus determined within the scope of this survey can be concluded to be related to need for lower prices (both CAPEX and OPEX), as well as need for fast deployment of infrastructure.

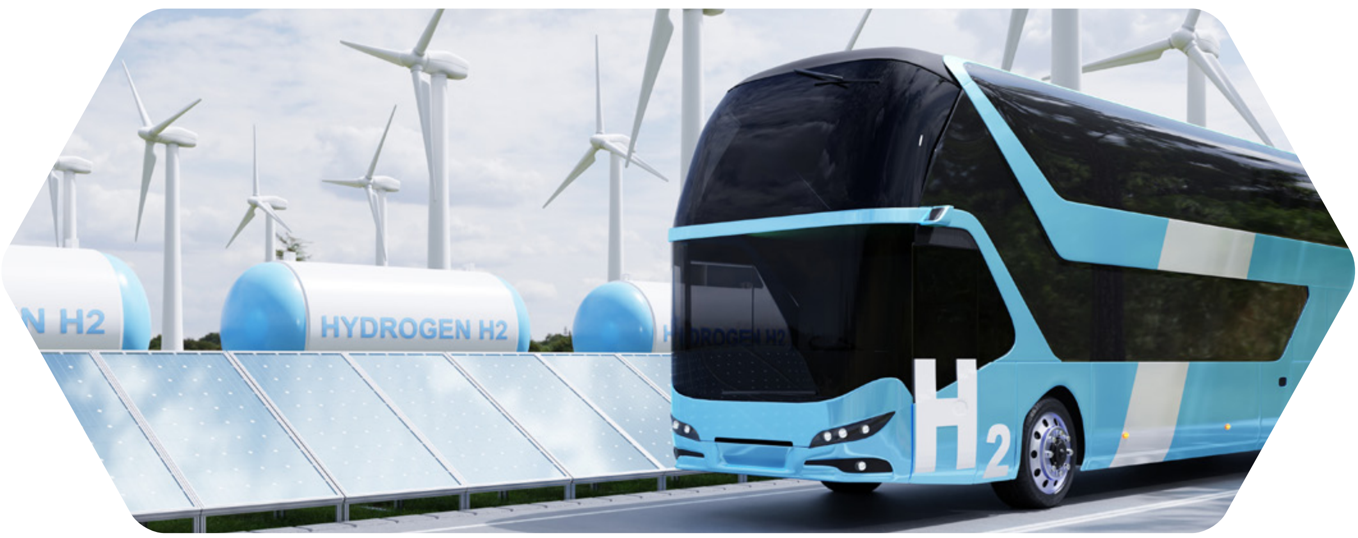


FIGURE 11

Bottlenecks and issues with H_2-powered buses and coaches

Cars and Vans

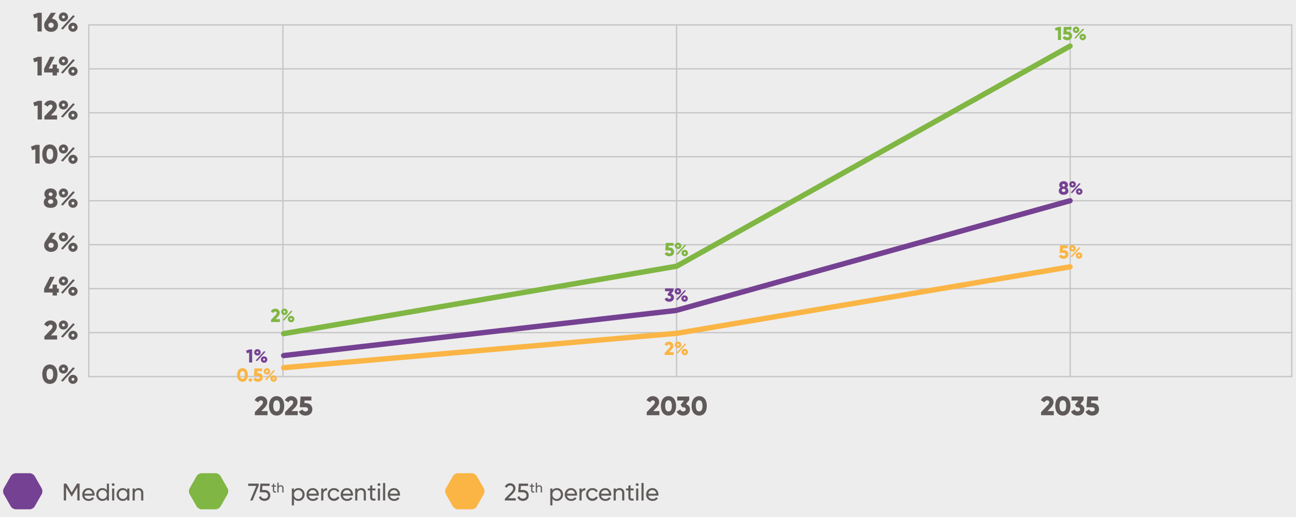
Determining the projection of cars and vans on the market, the initial question related to road sector was the following: **"What will be the penetration of H_2-powered cars and vans in Europe in 2025-2035?".** The results are presented in percentages for each observed year (5-year interval). The results are considered until 2035, as that is the year in which CO2 Emission Standards for Light Duty Vehicles mandate a 100% emission reduction of CO2 at tailpipe for cars and vans. We took that as a landmark date for the automotive industry and the culmination of a profound transformation process, which also includes delivering cleaner powertrains and vehicles thanks to the Euro 7 standards. Projections approaching the end of that decade would be too vague.

The results of the responses analysis are presented in **Figure 12**, based on the following assumptions:

- Data presents the penetration of new vehicles in the observed year.
- Responses presented as ranges are averaged between the lowest and highest estimation.
- Powertrains considered in the question are only fuel cell electric vehicles (FCEV) as this is currently the only powertrain available on the market.

FIGURE 12

Penetration of H_2-powered cars and vans in new vehicle sales in 2025-2035



In terms of long-term solutions for cars and vans, only three options were considered, which seemed the most viable:

- Battery-electric;
- Compressed gaseous hydrogen (at 700 bar) and
- Liquid hydrogen.

Based on this determination of the car and van types, the following results were obtained, with the full percentages presented in **Annex 6**:

FIGURE 13

Long-term solution for cars

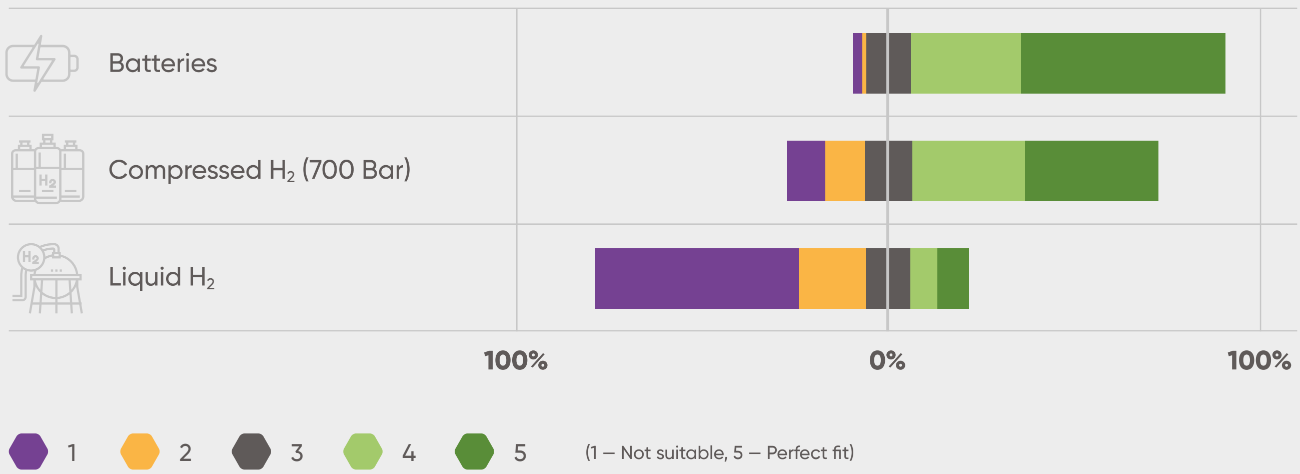
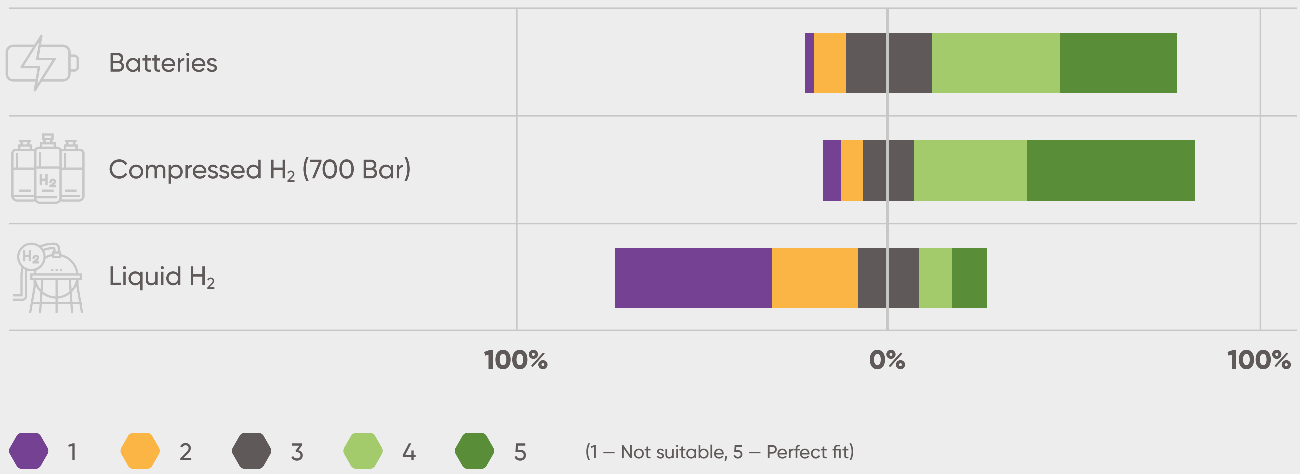


FIGURE 14

Long-term solution for vans



From the responses, it emerges that hydrogen-powered solutions are more applicable in larger vehicles, such as vans, while batteries are dominant in the car segment.

However, the choice of final solution is not that simple, as can be concluded from the figures:

- For **cars,** batteries show more potential, as the technology is (currently) more developed, with continuous progress. Moreover, there is a significant number of models available on the market, which cannot be said for hydrogen-powered cars. At the moment, there are only two models of fuel cell electric cars available on the European market – Toyota Mirai and Hyundai Nexo. However, with the increase of hydrogen car models (BMW, Range Rover, Toyota, etc.) and continued technology development, it will soon be up to the end-user whether they want to choose a battery-electric of fuel cell electric vehicle as both will be available.

- In terms of **vans,** the end-users already have a choice between battery-electric and hydrogen-powered vehicles. The choice depends on different factors – required operational range, overall vehicle weight, special energy needs (refrigerator, power outlets etc.), available cargo space and similar. The longer the daily operations, the heavier and larger the load, the more suitable hydrogen-powered vehicle becomes. At the current technology development range, batteries are at a disadvantage, as the more range is needed, the larger and heavier the battery is – meaning less cargo space. However, with technology development the future distribution might change, but it will highly depend on the needs of end-users.

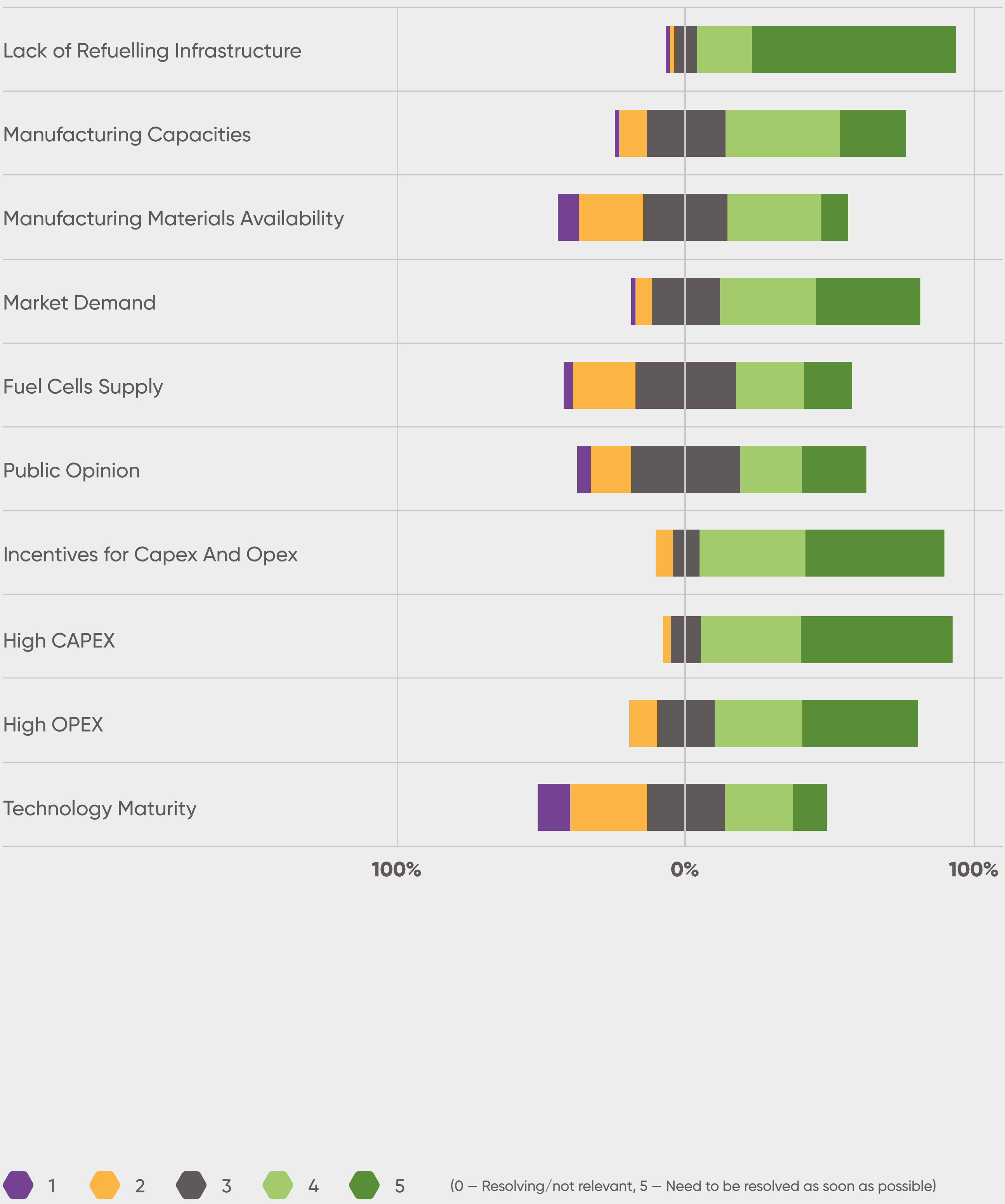
Furthermore, bottlenecks and issues with faster deployment of hydrogen-powered cars and vans were also examined, and the responses provided the results presented in **Figure 15** (while the details are presented in **Annex 7**). The figure shows four major bottlenecks that respondents believe need to be resolved as soon as possible (ranking of 5, with responses rate of over 40%):

- Lack of infrastructure (70.6%);
- High CAPEX (52.9%);
- Incentives for CAPEX (48.2%) and
- High OPEX (40.5%).

As is the case with previous hydrogen-powered road mobility segments, lack of infrastructure and funding are the main issues and bottlenecks in this segment as well. However, the lack of deployed infrastructure has quite a high score in this segment, as personal vehicles mainly depend on publicly available refuelling stations. The number of those in the EU is relatively small (around 200 in 2022), with a significant number not publicly available. Additionally, the price of hydrogen is also an issue (high OPEX), as it highly depends on the price of renewable electricity (via electrolysis – green hydrogen) or natural gas (grey/blue hydrogen).

FIGURE 15

Bottlenecks and issues with H_2-powered cars and vans



Hydrogen refuelling stations (HRS)

As presented in previous segments, HRS are the crucial point in faster deployment of hydrogen-powered vehicles. However, their deployment highly depends on the costs of roll-out, as well as operation, i.e. hydrogen costs at the HRS level.

Yet, with approval of AFIR, specific goals determined by 2030 will need to be satisfied, making it an obligation for Member States to make the hydrogen infrastructure publicly available for all end-users. This includes several specific points that need to be satisfied in order to achieve the minimum requirements, such as:

- One HRS each 200 km on the core TEN-T network;
- One HRS per each urban node as defined in the reviewed TEN-T Regulation[5];
- Daily capacity: 1 t H_2/day (cumulative) and
- Revision in 2026 will consider the inclusion of liquid hydrogen.

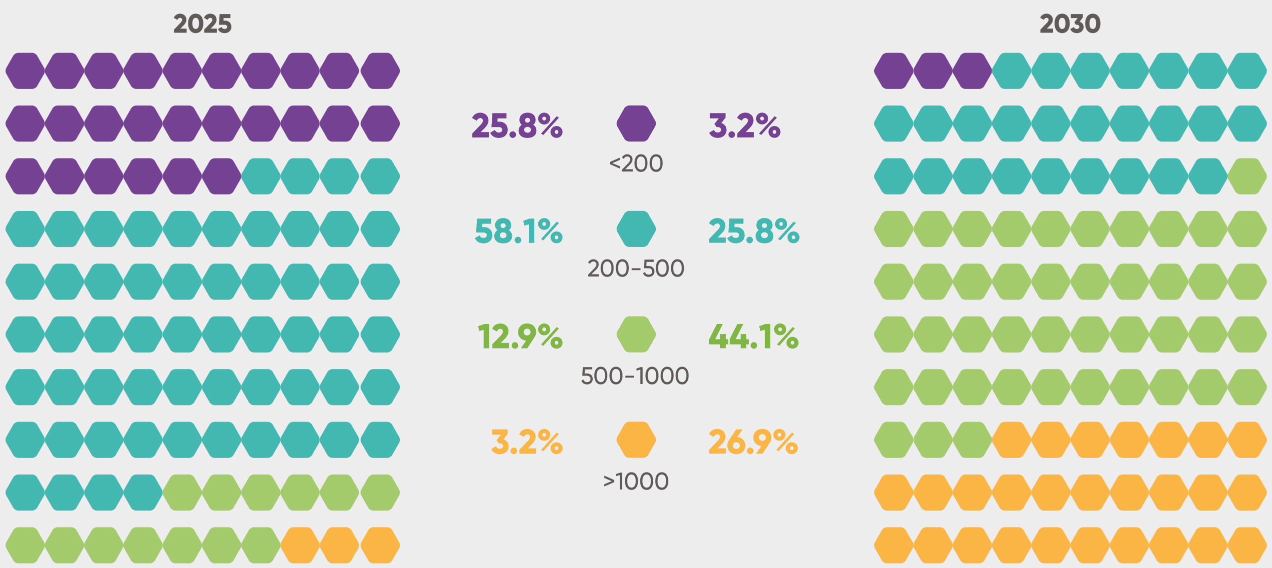
Therefore, to determine the uptake of HRS until 2030, the following question was put to the survey participants: **"What will be the number of available HRS in EU in 2025-2030?".** The results are presented for specific years, and determined with ranges, as the specific number of HRS deployed highly depends on Member States' plans, as well the deployment by manufacturers.

The results of the responses analysis are presented in **Figure 17**, based on the following assumptions:

- Numbers are presented in thousand euros and considered as the final price of HRS (standalone, without additional preparatory works, approvals, etc.).
- Responses presented as ranges are averaged between the lowest and highest estimation.

FIGURE 16

Number of high capacity HRS in operation



5 / European Parliament Legislative Observatory, 2021/0420(COD) - Trans-European Transport Network, January 2024.

As assumed, and which can be seen from the figure, the HRS network will grow to reach, by 2030, from current cca. 200 HRS, to between 500-1000 stations. These stations will be both standalone, as well as within a multi-fuel context.

In terms of technical specifications, the variety of parameters related to current stations, makes it very difficult to anonymously determine the averages or medians.

Additionally, financial issues vary from country to country. Yet, this survey tried to gather the cost data for different HRS configurations, which are the following:

- 500 kg daily capacity
- 1,000 kg daily capacity

FIGURE 17

HRS cost (in thousand EUR)

Maritime

In order to reduce emissions in the maritime sector, as well to increase the use of sustainable fuels, EU recently adopted the FuelEU Maritime Regulation[6]. The regulation mandates vessels above 5,000 gross tonnes calling at European ports to reduce greenhouse gas intensity of the energy used on board as follows:

- 2% until 2025;
- 6% until 2030;
- 14.5% until 2035;
- 31% until 2040;
- 62% until 2045 and
- 80% until 2050.

Although the regulation leaves it to ship operators to choose whichever technology to fulfill these targets, it defines a special incentive regime with a potential sub-quota in 2034 to support the uptake of renewable fuels of non-biological origin (RFNBO) with a high decarbonisation potential. In order to determine which fuels have most potential, this survey examined several options, considering different types of vessels. The question was set as: **"Please rate from 1-5 how suitable (in long-term) each fuel/technology is for different ships (main propulsion).",** where the considered vessels included:

- Cruise ships (example: cruiser, 60,000-99,999 GT[7]);
- Ferries, including ferry pax, ro-ro and ferry ro-pax (example: ferry ro-pax, 20,000+ GT);
- Bulk carriers (example: capsize bulk carrier, 60,000-100,000 DWT[8]);
- Container ships – feeder vessels (100-2,999 TEU[9]) and
- Large container ships (>3,000 TEU).

6 / European Commission, Regulation (EU) 2023/1805 of the European Parliament and of the Council of 13 September 2023 on the Use of Renewable and Low-Carbon Fuels in Maritime Transport, and Amending Directive 2009/16/EC, September 2023.
7 / GT = gross tonnage.
8 / DWT = deadweight tonnage.
9 / TEU = twenty-foot equivalent unit.

Based on this determination of the vessel types, the following results are obtained, with the full percentages presented in **Annex 8**:

FIGURE 18

Expected long-term solution for cruise ships (60,000 – 99,999 GT)

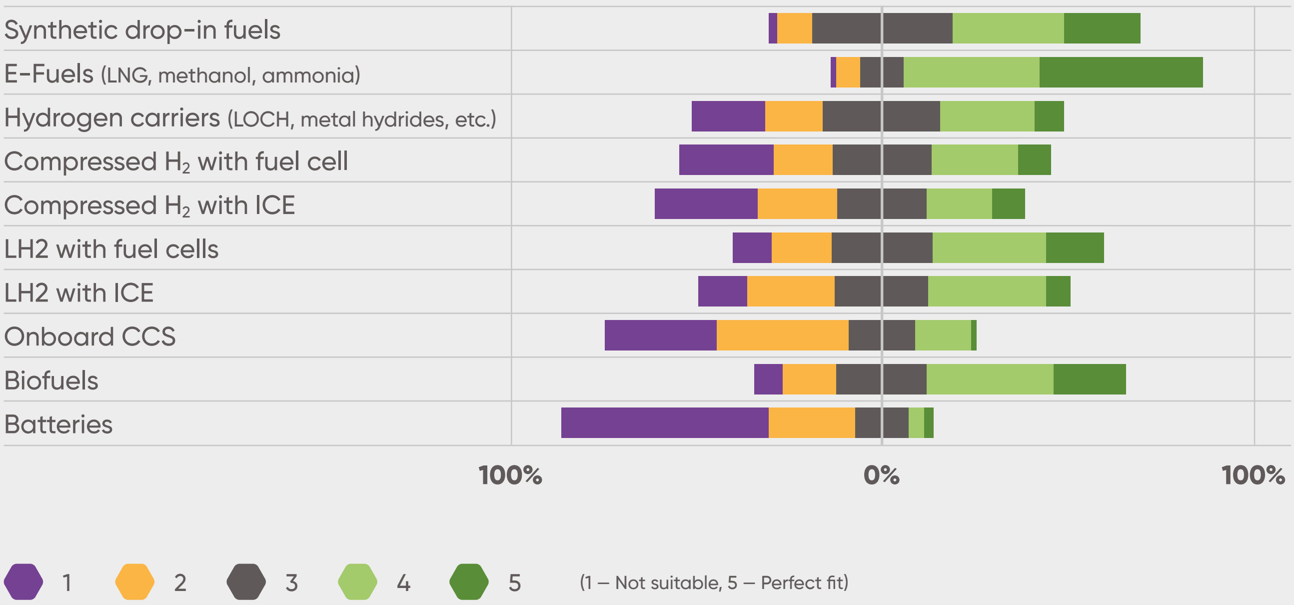


FIGURE 19

Expected long-term solution for ferries (over 20,000 GT)

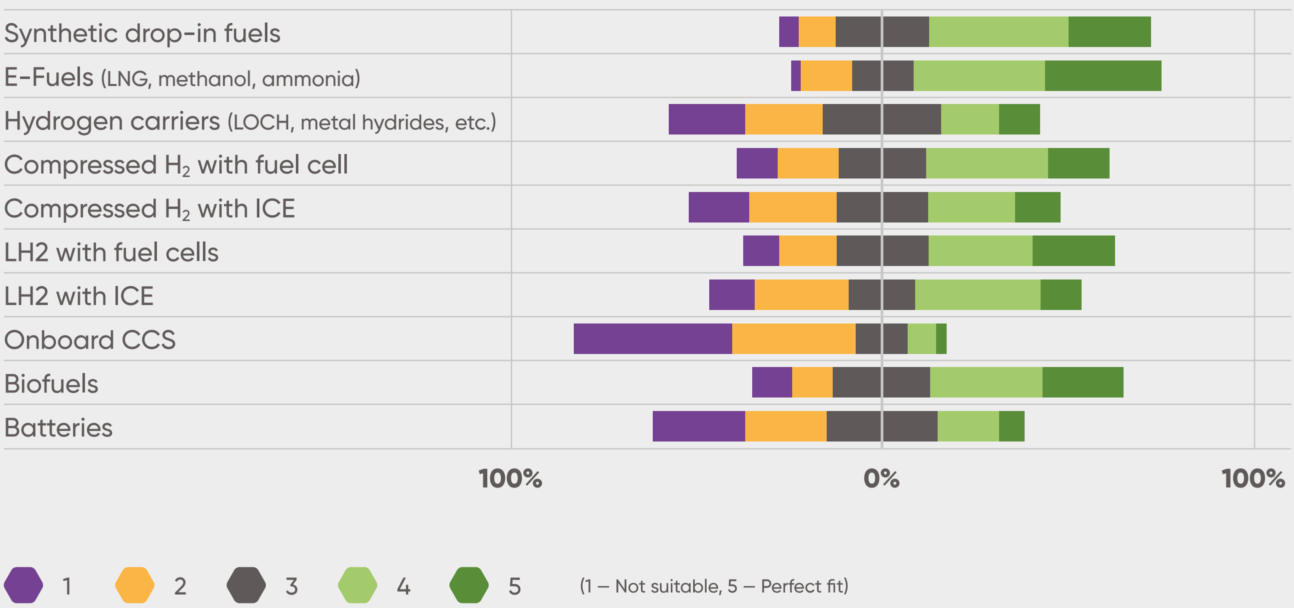


FIGURE 20

Expected long-term solution for bulk carriers (60,000 – 100,000 DWT)

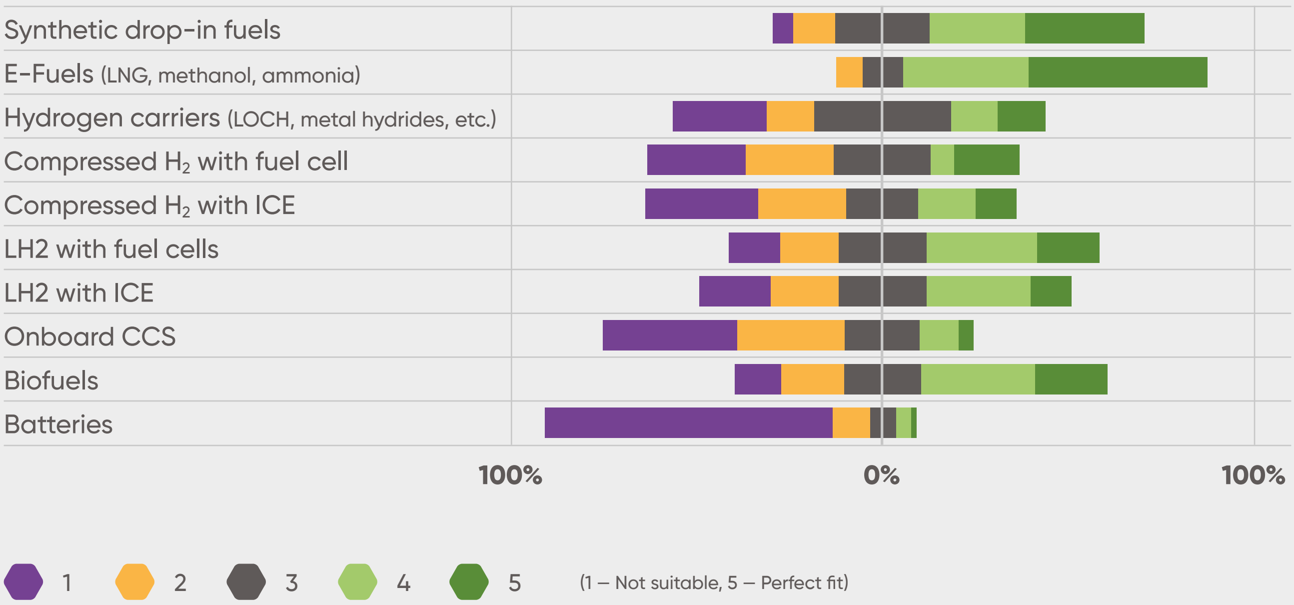


FIGURE 21

Expected long-term solution for container ships – feeder vessels (100 – 2,999 TEU)

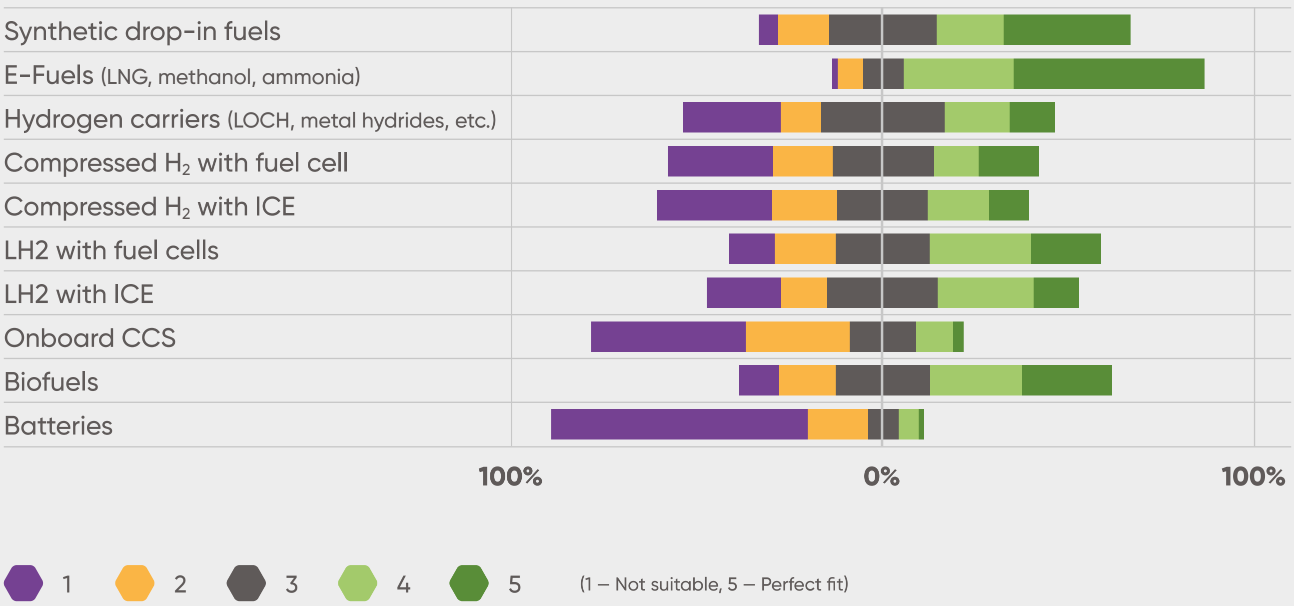
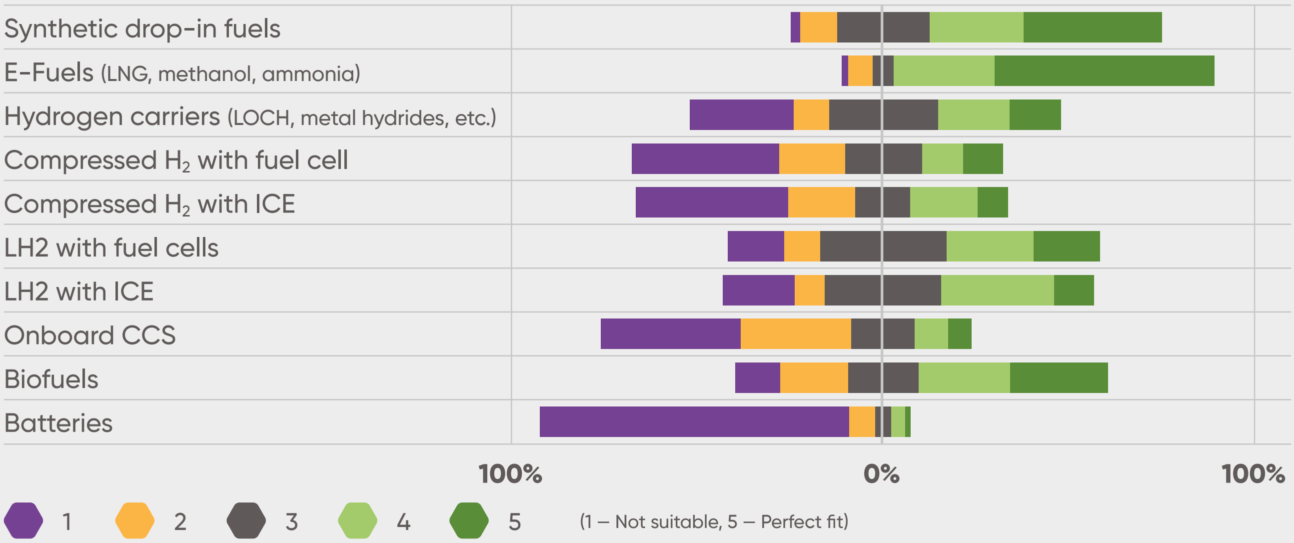


FIGURE 22

Expected long-term solution for large container ships (> 3,000 TEU)



As presented in results, it can easily be concluded that e-fuels are the most promising fuel for each vessel type, followed mainly by biofuels. Hydrogen is also suitable for most of the vessel types; though it is not considered a "perfect fit".

Still, considering the second most applicable solution[10], it is not very clear for each vessel types, as various solutions have their pros and cons:

- The most applicable solution considered for **cruise ships** by respondents is biofuels. Liquid hydrogen, in combination with fuel cell and internal combustion powertrains was selected as the next best option. Both options are considered carbon neutral, and can significantly contribute to emissions reduction, without losing the energy needed to power such large vessels.

- In case of **ferries,** synthetic drop-in fuels are considered as the best fit, due to lack of need for retrofitting. Vessels, including ferries, have a long lifetime, meaning that it is not feasible to do a retrofit to decarbonised fuels, but it is simpler to add emission-reducing fuels. It should also be considered that this specific vessel type usually runs on rather short and fixed routes with frequent refuelling; this would bypass hydrogen's low energy density, thus making it a good choice. Therefore, it is not surprising to see that responders indicated hydrogen as the next best fit – both liquid hydrogen combined with internal combustion engines (for longer distances) and compressed gaseous hydrogen combined with fuel cell (for short distances). Biofuels are also considered a good fit, as they reduce emissions and provide enough power to cover the energy demand.

- In **bulk carriers,** the dominant fuels of the future are synthetic drop-in fuels and biofuels – which are considered due to their option for adapting the fuels to existing engines, and not requiring complete retrofit, or new vessel manufacturing.

- **Container ships** have a similar situation with the results, as they are large vessels with a long lifetime, which require as little adaptation as possible, in order to continue their operation, while simultaneously reducing emissions. However, in larger container ships, liquid hydrogen in combination with internal combustion engines presents itself as an option – this solution is relatively new on the market but showing a lot of promise to provide the necessary power needed, while research has shown that it might be possible to retrofit existing engines to use hydrogen as fuel.

10 / E-fuels will be excluded from further analysis, as it is considered the best option in all vessel types.

Furthermore, bottlenecks and issues with faster deployment of hydrogen-powered vessels were also examined, and the responses provided the results presented in **Figure 23** (while the details are presented in **Annex 9**). The figure shows four major bottlenecks that respondents consider need to be resolved as soon as possible (ranking of 5, with responses rate of over 40%):

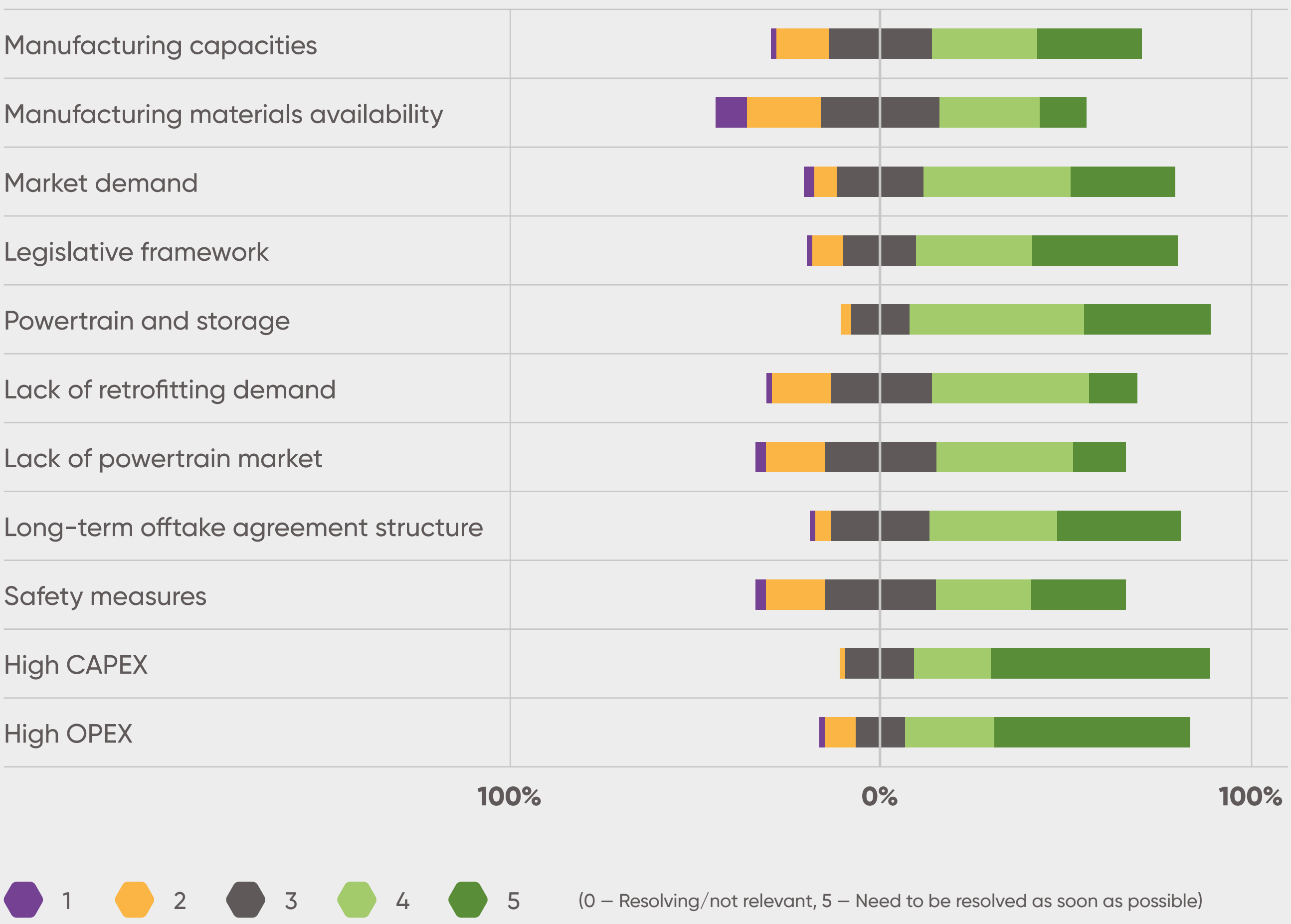
- High CAPEX (59.4%);
- High OPEX (52.9%);
- Powertrain and storage (47.1%) and
- Lack of retrofitting (42.9%).

Due to high prices of large vessels, it is not unusual that these bottlenecks are the most selected ones, especially since hydrogen-powered solutions currently have higher prices (both CAPEX and OPEX) than their fossil-fuel counterparts. Moreover, the next bottleneck (powertrain and storage) follows up on the first one, as there are several options for hydrogen-powered vessels to be implemented – fuel cells and internal combustion engines in terms of powertrain; and gaseous hydrogen (350 and 700 bar pressures) and liquid hydrogen in terms of storage.

Lack of retrofitting is also a bottleneck, due to high costs of this activity. The combinations for hydrogen-powered vessels (in terms of powertrain and storage) can significantly differ from vessel to vessel, and especially in cost.

FIGURE 23

Bottlenecks and issues with H_2-powered vessels



Aviation

The regulation on Ensuring a Level-Playing Field for Sustainable Air Transport (also known as the ReFuelEU Aviation Regulation[11]) aims to increase the uptake of sustainable fuels by aircraft to reduce their environmental footprint. These sustainable fuels can be advanced biofuels, recycled carbon fuels, synthetic aviation fuels (RFNBOs), but hydrogen for aviation and synthetic low carbon aviation fuels are also eligible. The minimum shares are determined, and need to be implemented on a set timeline:

- 2% by 2025;
- 6% by 2030;
- 20% by 2035;
- 34% by 2040;
- 42% by 2045 and
- 70% by 2050.

In order to determine which fuels have most potential, this survey examined several options, considering different distances needed to be covered by passenger aircraft. The question was set as: **"Please rate from 1-5 how suitable (in long-term) each fuel is for specific range flights."**, where the considered distances included:

- Very short-range flights: <500 km;
- Short-range flights: 500-1,500 km;
- Medium-range flight: 1,501-4,000 km and
- Long-range flight: >4,000 km.

11 / European Commission, Regulation (EU) 2023/2405 of the European Parliament and of the Council of 18 October 2023 on Ensuring a Level Playing Field for Sustainable Air Transport (ReFuelEU Aviation), October 2023.

Based on this determination of the distances covered by aircraft, the following results are obtained, with the full percentages presented in **Annex 10**:

FIGURE 24

Long-term solution for very short-range flights (<500 km)

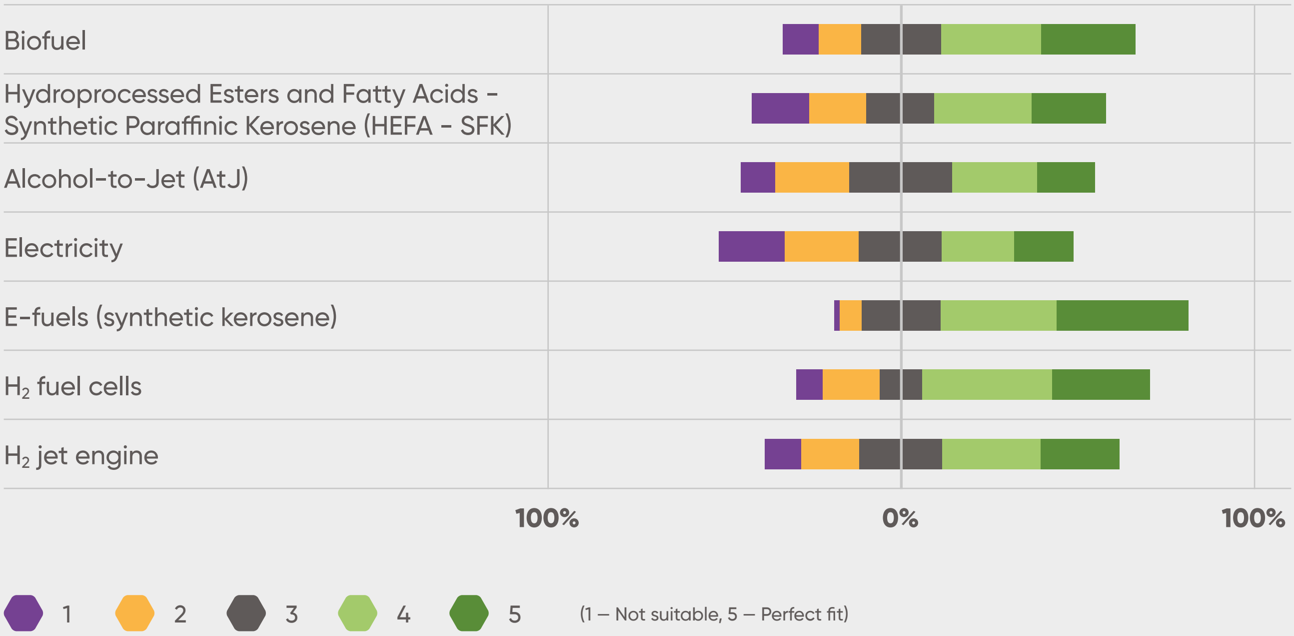


FIGURE 25

Long-term solution for short-range flights (500-1,500 km)

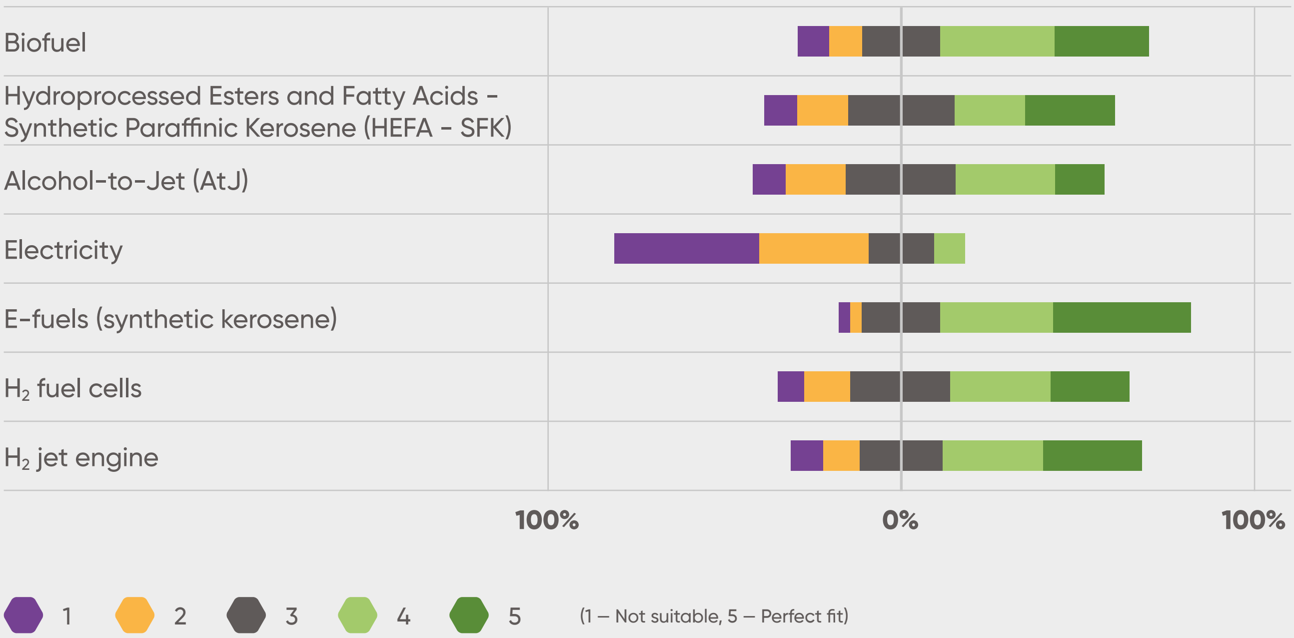


FIGURE 26

Long-term solution for medium-range flights (1,501-4,000 km)

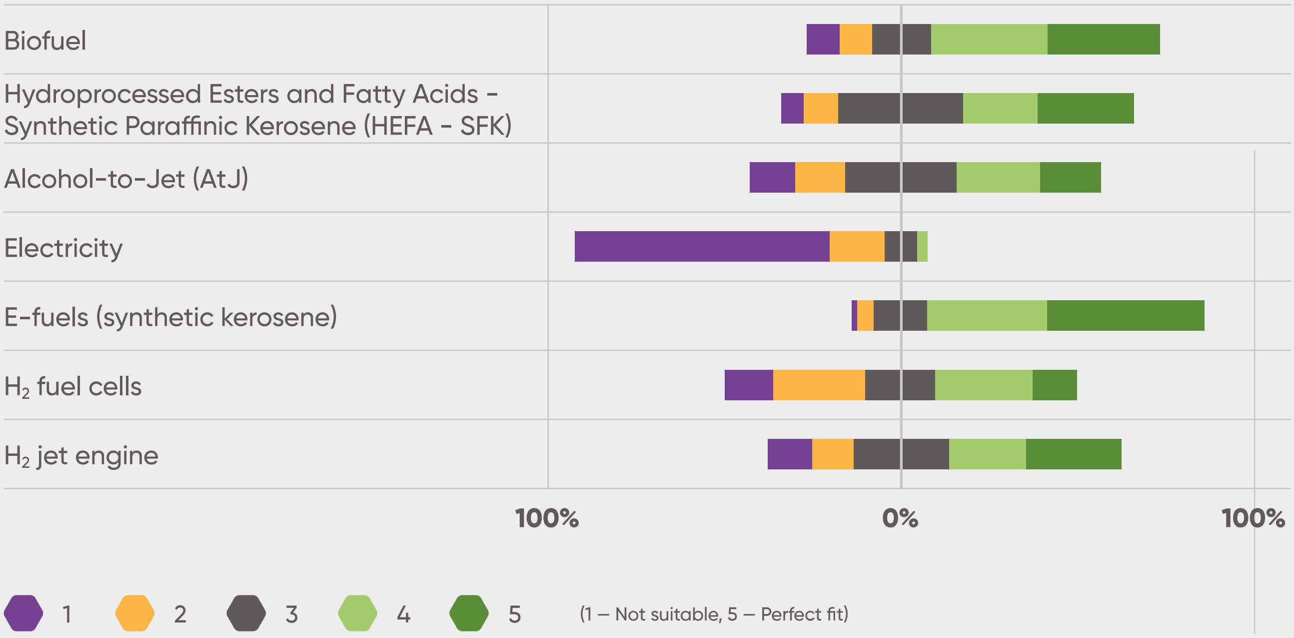
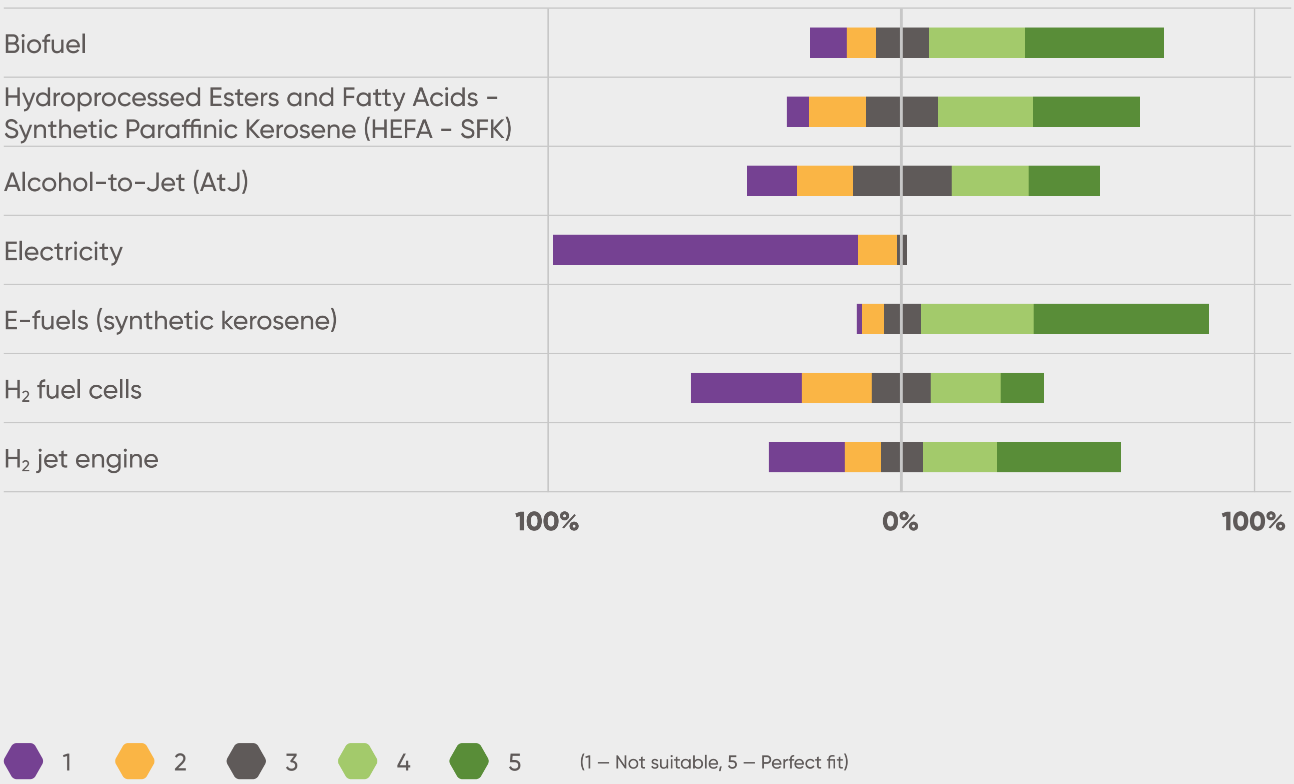


FIGURE 27

Long-term solution for long-range flights (>4,000 km)



The most promising long-term solution for all the considered distances proved to be synthetic kerosene, a sustainable aviation fuel (SAF). Other fuels also have potential for the future, especially in terms of very-short range flights – in this segment, all the solutions are possible, even electricity. However, the larger the distance, the less electricity becomes viable, turning the attention of respondents to other fuels, such as biofuels, HEFA, AtJ and hydrogen.

In terms of hydrogen, it shows a lot of potential, both in fuel cells and jet engine combustion powertrains. Yet, both technologies in the aviation sector are still in development phase, with a lot of promises showing already in the early stages of various projects. Although combustion in jet engines has lower efficiency rates, it provides enough energy to power the aircraft for longer periods.

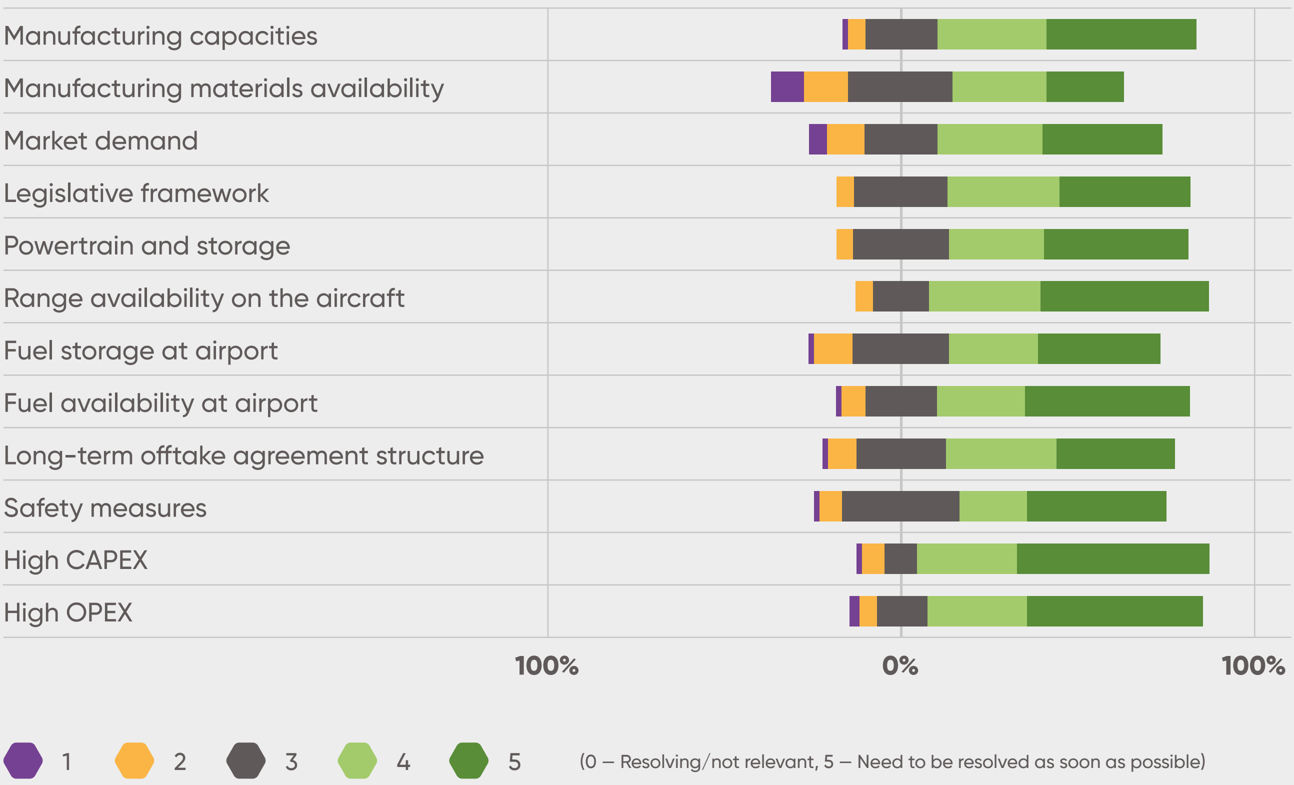
Furthermore, bottlenecks and issues with faster deployment of hydrogen-powered aircraft were also examined, and the responses provided the results presented in **Figure 28** (while the details are presented in **Annex 11**). In contrast to previous sectors, aviation has several more challenges (ranking of 5, with responses rate of over 40%) that need to be surpassed, in order to have the proper uptake of hydrogen-powered aircraft on the market:

- High CAPEX (54.7%);
- High OPEX (50.0%);
- Range availability (47.6%);
- Fuel availability (46.9%);
- Manufacturing capacities (42.2%) and
- Powertrain and storage (41.3%).

Considering that hydrogen-powered aviation is still in its infancy, these are standard bottlenecks that need to be resolved in order to achieve commercialisation. However, fuel availability might be a significant bottleneck, as aircraft will require large amounts of hydrogen to cover larger distances (either in gaseous or liquid form). This needs to be resolved within the regulatory framework, as well as with direct communication with hydrogen producers, in order to ensure the required amount of hydrogen needed in this sector.

FIGURE 28

Bottlenecks and issues with H_2-powered aircraft



Conclusions

The survey aimed at gauging industry's commitments and predictions for the development of hydrogen in the whole transport sector. Responses aggregated in the report highlight a great interest in alternative fuels for all modes of transport as well as a certain degree of confidence that hydrogen-based technologies will scale up and be widely used in all applications and market segments if the proper preconditions are met.

For the large-scale deployment of hydrogen powered fleets, **clear policy signals must be provided, and infrastructure investments must be made beforehand:** vehicles cannot be operated without a dense network of hydrogen refuelling infrastructure, aircraft and vessels cannot be decarbonised without wide availability of green fuels.

Therefore, Hydrogen Europe recommends that a coherent policy landscape is put in place; **Fit for 55 laws that are currently being finalised must be complemented by the revision of existing files that can shoulder the European Green Deal package and send further positive signal for the transition towards zero-emission transport.** Topics such as (but not limited to) air quality, energy taxation, road charging, renewable energy, industrial development, end of life, emission trading in all modes of transport, and carbon credits must be reviewed to provide a comprehensive and encouraging framework for the development of hydrogen-based mobility solutions. Deployment targets, mandates and timelines must also be consistent not just from a purely timing perspective but also with the deployment on enabling conditions, the first of which are refuelling infrastructure and the availability of reasonably priced hydrogen. In this respect, Hydrogen Europe maintains that **the 2030 deployment target set in Article 6 of the Alternative Fuels Infrastructure Regulation should be the starting point for the ramp up of hydrogen technologies in road transport,** where every other target is linked to it. But we also see the need to change the taxation rates for clean energy carriers in the transport sector and to create availability of additional financial resources for de-risking the investments and operations of hydrogen fleets and HRS infrastructure.

A wide availability of green fuels (green hydrogen and derivatives) is a critical factor in the decarbonisation of mobility. However, the cost of hydrogen is often a significant barrier to the widespread deployment of hydrogen mobility solutions, as results show in this survey. Hydrogen Europe thus calls on the European and national level to **incentivise investment in clean hydrogen production through targeted support and the easing of regulatory barriers; as well as increasing funding opportunities** for development of fleets and innovation on hydrogen vehicles/vessels/planes. The implementation of the ambitious target and regulatory framework of the European Union on mobility will require significant investment from all operators but will not happen without temporary support schemes to reduce the cost difference compared with conventional mobility solutions.

Advancements in hydrogen technologies for mobility and their widespread development in the EU will also see a need for common standardization on manufacturing processes for new vehicles, and common certification schemes for fuels used. **These processes need to be developed together with the international level, especially for the maritime and aviation sector, both being global per nature.** Stable regulatory and standardisation processes need to be given certainty in order to ramp up production and deployment of hydrogen mobility solutions across the EU.

Finally, we note the increasing importance of tackling the subject of public awareness and acceptance of hydrogen as a viable and safe fuel for the success of hydrogen mobility. Addressing concerns related to safety and educating the public about the benefits of hydrogen is crucial for a wide adoption of hydrogen technologies.


H2
Hydrogen
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Annex 1 | Methodological note

Methodology and questionnaire

Prior to the survey, a questionnaire was developed by HE, for HE members (Membership) to determine the priority topics the survey should cover. As the focus of the survey was directed towards the mobility sector, the questionnaire was initially sent out to HE's Mobility Working Group (MOWG). MOWG is one of HE's working groups, focusing on coordinating, collecting and amplifying members' input into the advocacy work developed by the CEO and the Secretariat team on high priority, cross-cutting issues pertaining to the mobility sector as a whole, such as the Trans-European Network for Transport and the deployment of hydrogen refuelling infrastructure for all modes of transport.

The importance of several data categories was examined, most important of which are presented in the following tables. Priorities were determined based on the question importance, ranking from "Not useful and/or applicable" to "High priority".

TABLE 2

Results of the questionnaire for road sector in Europe

QUESTION	HIGH PRIORITY RESULT (%)
Technical specification of the technology (aggregated to a specific: refuelling time, range, efficiency, CAPEX and similar)	57%
Suitability of specific powertrains to different road vehicles categories	50%
Type of technology (FCEV, H2ICE, retrofit) used in those (planned/projected) vehicles	73%
Projected/planned number of road vehicles (cars, vans, trucks, buses) in the following 5- or 10-year periods (2025-2050) in Europe	73%
Number of road vehicles (cars, vans, trucks, buses) in the last year in Europe	50%

TABLE 3

Results of the questionnaire for maritime sector in Europe

QUESTION	HIGH PRIORITY RESULT (%)
Technical specification of the technology (aggregated to a specific: refuelling time, range, efficiency, CAPEX and similar)	62%
Dominant long-term zero-emission fuel solution for maritime in Europe	58%
Penetration of hydrogen in maritime sector (% in 5- or 10-year intervals from 2025 to 2050) in Europe	77%
Penetration of e-fuels in maritime sector (% in 5- or 10-year intervals from 2025 to 2050)	57%
Usage of e-fuels in maritime sector in previous year	34%

TABLE 4

Results of the questionnaire for aviation sector in Europe

QUESTION	HIGH PRIORITY RESULT (%)
Technical specification of the technology (aggregated to a specific: refuelling time, range, efficiency, CAPEX and similar)	53%
Dominant long-term zero-emission fuel solution for aviation in Europe	60%
Penetration of hydrogen in aviation sector % in 5- or 10-year intervals from 2025 to 2050)	69%
Penetration of sustainable aviation fuels (SAF) in aviation sector (% in 5- or 10-year intervals from 2025 to 2050) in Europe	65%
Usage of sustainable aviation fuels (SAF) in aviation sector in previous year	28%

TABLE 5

Results of the questionnaire for HRS infrastructure in Europe

QUESTION	HIGH PRIORITY RESULT (%)
Technical specification of the technology (aggregated to a specific: refuelling time, range, efficiency, CAPEX and similar)	62%
Estimation of HRS daily capacities in different European corridors (road vehicles)	66%
Largest HRS users (HDV, buses, cars, vans) in Europe	62%
Used hydrogen in HRS in Europe during last year	57%
Projected/planned number of HRS for road vehicles in the following 5- to 10-year intervals from 2025 to 2050	81%

Additionally, the participants were asked to determine the importance of bottlenecks and issues occurring in the hydrogen mobility sector, ranking them with the following grades:

- Not useful and/or applicable,
- Valuable data, but cannot be gathered via survey,
- Somewhat important and
- High priority.

The results are shown in the following table.

TABLE 6

Results of the questionnaire on possible bottlenecks

QUESTION	NOT USEFUL AND/OR APPLICABLE	VALUABLE DATA, BUT CANNOT BE GATHERED VIA SURVEY	SOMEWHAT IMPORTANT	HIGH PRIORITY
Opinions/positions on the **MARKET** bottlenecks for faster uptake of hydrogen-powered technologies	3%	5%	42%	49%
Opinions/positions on the **TECHNICAL** bottlenecks for faster uptake of hydrogen-powered technologies	3%	11%	33%	53%
Opinions/positions on the **LEGISLATIVE** bottlenecks for faster uptake of hydrogen-powered technologies	3%	5%	44%	48%

Based on the responses provided by the respondents, a survey was developed, focusing on the segments that had the highest rankings and priorities in the questionnaire (50% and above). However, in order to objectify the responses provided in the survey, the data should be provided by market participants themselves, i.e. manufacturers, producers, end-users providing their market plans and data. As that is not possible, nor this data available (as it would lead to confidentiality issues), the question selection was based on information that could be anonymised.

Therefore, the developed survey was anonymous, requiring information that does not challenge the confidentiality of the participants providing their inputs. However, this meant that some of the selected and relevant questions from the questionnaire could not be asked.

Respondents

The survey was fulfilled by 99 experts, in the period of June 13th 2023, until September 15th 2023. As the survey was anonymous, it was not possible to obtain data on the participants. However, to provide the scope within which they are working in, several questions were asked to determine their expertise in the mobility sector. The results are presented within the following figures.

From **Figure 1**, it can be seen that the majority of respondents come from industry, followed by SMEs and national associations. In terms of the 'other' category, respondents mentioned the following organisation type: mobility company, regional NGO/association, cluster, region, transport company, engineering and construction contractor and energy agency.

Examining the activities of these organisations was done through the following question, where the results are presented in **Figure 2**.

Although Mobility is less represented, the Industry, Fuel production and Transportation (intended as distribution of hydrogen across the continent) segments are extremely relevant to mobility, as the respondents mentioned in further comments that some of them are manufacturers (manufacturing components for the mobility segment), as well as fuel producers for mobility. In terms of Transportation, it is also needed in the mobility segment, bringing the hydrogen to refuelling stations. Additionally, it was possible to select several sectors, which explains why the majority is related to industry.

In terms of the geographical activities of the respondents, most of them are covering global market, with the focus on European market, while 35% are focused strictly on the European Union market (**Figure 31**).

Considering that respondents to the survey are all members of Hydrogen Europe, the results ought to be relevant, as all of them have significant experience along the hydrogen value chain. As the survey was conducted on a voluntary basis, it is assumed that most respondents consider mobility to be part of their business – either directly (manufacturing of vehicles/vessels/aircraft, end-users) or indirectly (providing hydrogen for refuelling, manufacturing of components/ providing necessary infrastructure).

FIGURE 29

Organisation type of the respondents

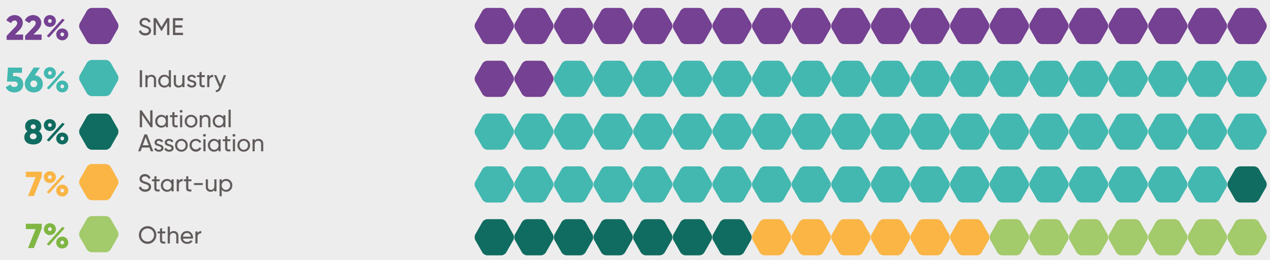


FIGURE 30

Hydrogen sector in which the organisation is present and active

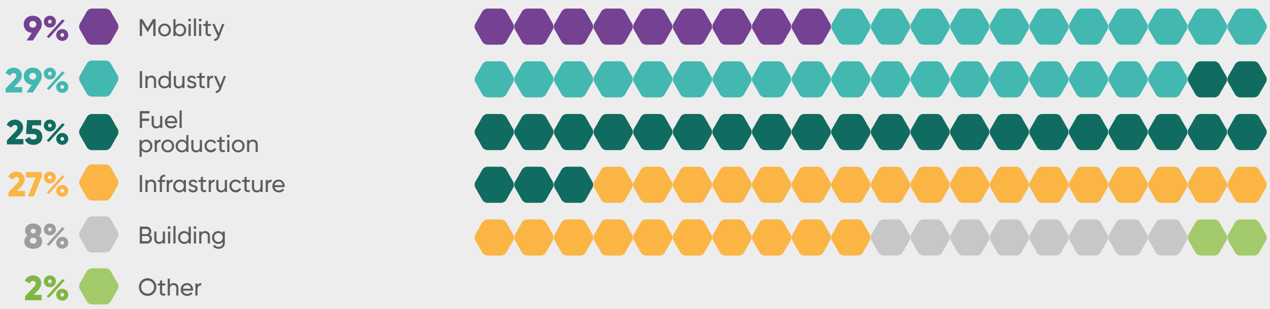
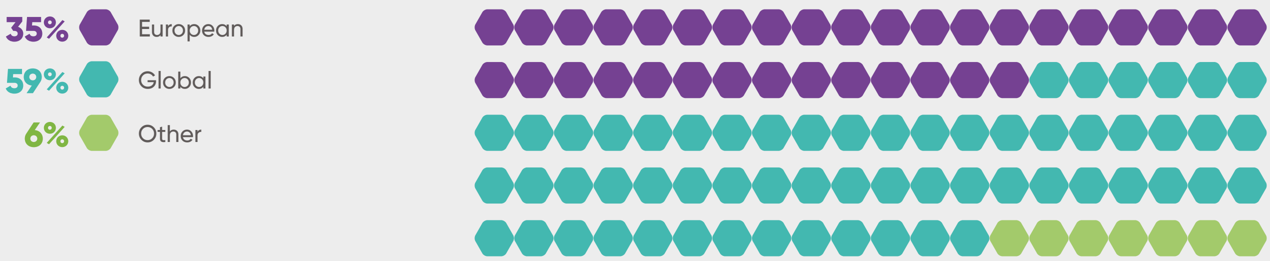


FIGURE 31

Geographical scope of market activities



Annex 2 | Long-term solutions for hydrogen-powered trucks: complete results

Ranking determined in range from 1 – **"not suitable"** to 5 – **"perfect fit"**.

TABLE 7

Long-term solution for long-haul trucks

	Batteries	Compressed H_2 (350 bar)	Compressed H_2 (700 bar)	Liquid H_2
1	44.6 %	5.4 %	0.0 %	6.6 %
2	31.5 %	15.1 %	4.3 %	12.1 %
3	15.2 %	41.9 %	15.1 %	11.0 %
4	7.6 %	28.0 %	43.0 %	19.8 %
5	1.1 %	9.7 %	37.6 %	50.5 %

Long-term solution for regional delivery trucks

	Batteries	Compressed H_2 (350 bar)	Compressed H_2 (700 bar)	Liquid H_2
1	5.4 %	1.1 %	2.2 %	19.8 %
2	20.7 %	9.7 %	12.0 %	23.1 %
3	29.3 %	21.5 %	20.7 %	26.4 %
4	28.3 %	47.3 %	30.4 %	15.4 %
5	16.3 %	20.4 %	34.8 %	15.4 %

Long-term solution for urban delivery trucks

	Batteries	Compressed H_2 (350 bar)	Compressed H_2 (700 bar)	Liquid H_2
1	1.1 %	9.9 %	14.4 %	40.0 %
2	3.3 %	12.1 %	15.6 %	30.0 %
3	11.0 %	22.0 %	27.8 %	13.3 %
4	26.4 %	31.9 %	21.1 %	8.9 %
5	58.2 %	24.2 %	21.1 %	7.8 %

Long-term solution for municipal utility trucks

	Batteries	Compressed H_2 (350 bar)	Compressed H_2 (700 bar)	Liquid H_2
1	1.1 %	9.7 %	15.4 %	39.3 %
2	5.4 %	11.8 %	12.1 %	20.2 %
3	23.9 %	14.0 %	18.7 %	20.2 %
4	34.8 %	34.4 %	22.0 %	11.2 %
5	34.8 %	30.1 %	31.9 %	9.0 %

Annex 3 | Bottlenecks and issues for faster deployment of H_2-powered trucks

Ranking determined in range from 0 – **"resolving/not relevant"** to 5 – **"need to be resolved as soon as possible".**

TABLE 8

Bottlenecks and issues for faster deployment of H_2-powered trucks

	1	2	3	4	5
Lack of infrastructure	0.0 %	1.1 %	11.7 %	21.3 %	66.0 %
Manufacturing capacity	0.0 %	6.5 %	31.2 %	35.5 %	26.9 %
Manufacturing materials availability	4.3 %	21.5 %	33.3 %	34.4 %	6.5 %
Market demand	3.2 %	17.2 %	24.7 %	25.8 %	29.0 %
Legislative framework	0.0 %	10.6 %	23.4 %	33.0 %	33.0 %
Fuel cells supply	3.2 %	14.0 %	36.6 %	32.3 %	14.0 %
Public opinion	8.5 %	26.6 %	35.1 %	22.3 %	7.4 %
Lack of incentives for buyers	0.0 %	6.4 %	16.0 %	34.0 %	43.6 %
Homologation process	4.4 %	14.3 %	39.6 %	25.3 %	16.5 %
High CAPEX	0.0 %	1.1 %	6.4 %	43.6 %	48.9 %
High OPEX	1.1 %	9.6 %	13.8 %	37.2 %	38.3 %
Dimensions and weights	9.6 %	29.8 %	36.2 %	12.8 %	11.7 %

Annex 4 | Long-term solutions for hydrogen-powered buses and coaches: complete results

Ranking determined in range from 1 – **"not suitable"** to 5 – **"perfect fit".**

TABLE 9

Long-term solution for urban buses (distances up to 300km)

Rank	Batteries	Compressed H_2 (350 bar)	Compressed H_2 (700 bar)	Liquid H_2
1	3.5 %	8.1 %	8.2 %	34.5 %
2	10.6 %	11.6 %	15.3 %	26.2 %
3	23.5 %	17.4 %	30.6 %	17.9 %
4	35.3 %	33.7 %	17.6 %	11.9 %
5	27.1 %	29.1 %	28.2 %	9.5 %

Long-term solution for intercity buses (distances between 300 and 500km)

Rank	Batteries	Compressed H_2 (350 bar)	Compressed H_2 (700 bar)	Liquid H_2
1	20.2 %	2.3 %	4.8 %	20.2 %
2	29.8 %	11.6 %	7.1 %	11.9 %
3	35.7 %	31.4 %	9.5 %	17.9 %
4	8.3 %	34.9 %	27.4 %	29.8 %
5	6.0 %	19.8 %	51.2 %	20.2 %

Long-term solution for coaches (distances above 500km)

Rank	Batteries	Compressed H_2 (350 bar)	Compressed H_2 (700 bar)	Liquid H_2
1	56.6 %	1.2 %	2.3 %	9.4 %
2	22.9 %	29.1 %	7.0 %	8.2 %
3	10.8 %	36.0 %	7.0 %	11.8 %
4	6.0 %	22.1 %	30.2 %	23.5 %
5	3.6 %	11.6 %	53.5 %	47.1 %

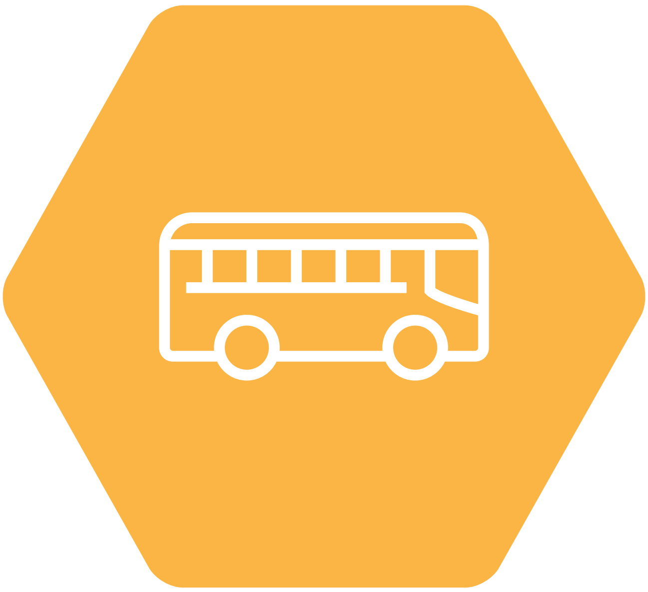
Annex 5 | Bottlenecks and issues for faster deployment of H_2-powered buses and coaches

Ranking determined in range from 0 – **"resolving/not relevant"** to 5 – **"need to be resolved as soon as possible".**

TABLE 10

Bottlenecks and issues for faster deployment of H_2-powered buses and coaches

	1	2	3	4	5
Lack of infrastructure	0.0 %	2.3 %	17.2 %	23.0 %	57.5 %
Manufacturing capacities	0.0 %	12.8 %	23.3 %	43.0 %	20.9 %
Manufacturing materials availability	5.8 %	23.3 %	33.7 %	29.1 %	8.1 %
Market demand	4.7 %	12.8 %	32.6 %	25.6 %	24.4 %
Legislative framework	1.2 %	11.6 %	24.4 %	30.2 %	32.6 %
Fuel cells supply	3.5 %	19.8 %	36.0 %	30.2 %	10.5 %
Public opinion	10.5 %	16.3 %	41.9 %	19.8 %	11.6 %
Lack of incentives	0.0 %	8.1 %	17.4 %	34.9%	39.5 %
Homologation process	5.9 %	15.3 %	34.1 %	28.2 %	16.5 %
High CAPEX	0.0 %	0.0 %	9.2 %	33.3 %	57.5 %
High OPEX	1.1 %	4.6 %	14.9 %	32.2 %	47.1 %



Annex 6 | Long-term solutions for hydrogen-powered cars and vans: complete results

Ranking determined in range from 1 – **"not suitable"** to 5 – **"perfect fit".**

TABLE 11

Long-term solution for cars

Rank	Batteries	Compressed H_2 (700 bar)	Liquid H_2
1	2.4 %	10.5 %	54.8 %
2	1.2 %	10.5 %	17.9 %
3	11.8 %	12.8 %	11.9 %
4	29.4 %	30.2 %	7.1 %
5	55.3 %	36.0 %	8.3 %

Long-term solution for vans

Rank	Batteries	Compressed H_2 (700 bar)	Liquid H_2
1	2.4 %	4.7 %	42.2 %
2	8.2 %	5.8 %	22.9 %
3	23.5 %	14.0 %	16.9 %
4	34.1 %	30.2 %	8.4 %
5	31.8 %	45.3 %	9.6 %

Annex 7 | Bottlenecks and issues for faster deployment of H_2-powered cars and vans

Ranking determined in range from 0 – **"resolving/not relevant"** to 5 – **"need to be resolved as soon as possible".**

TABLE 12

Bottlenecks and issues for faster deployment of H_2-powered cars and vans

	1	2	3	4	5
Lack of infrastructure	1.2 %	1.2 %	8.2 %	18.8 %	70.6 %
Manufacturing capacities	1.2 %	9.4 %	27.1 %	40.0 %	22.4 %
Manufacturing materials availability	7.1 %	22.4 %	29.4 %	31.8 %	9.4 %
Market demand	1.2 %	5.9 %	23.5 %	32.9 %	36.5 %
Fuel cells supply	3.5 %	21.2 %	35.3 %	23.5 %	16.5 %
Public opinion	4.7 %	14.1 %	37.6 %	21.2 %	22.4 %
Incentives for CAPEX	0.0 %	5.9 %	9.4 %	36.5 %	48.2 %
High CAPEX	0.0 %	2.4 %	10.6 %	34.1 %	52.9 %
High OPEX	0.0 %	9.5 %	20.2 %	29.8 %	40.5 %
Technology maturity	11.8 %	25.9 %	27.1 %	23.5 %	11.8 %

Annex 8 | Long-term solutions for hydrogen-powered vessels: complete results

Ranking determined in range from 1 – **"not suitable"** to 5 – **"perfect fit".**

TABLE 13

Technology suitability for cruise ships (60,000 – 99,999 GT)

	1	2	3	4	5
Synthetic drop-in fuels	2.6 %	9.1 %	37.7 %	29.9 %	20.8 %
E-fuels	1.3 %	6.5 %	11.7 %	36.4 %	44.2 %
LOHC	19.7 %	15.8 %	31.6 %	25.0 %	7.9 %
Compressed H_2 FC	25.6 %	15.4 %	26.9 %	23.1 %	9.0 %
Compressed H_2 ICE	28.0 %	21.3 %	24.0 %	17.3 %	9.3 %
LH_2	10.5 %	15.8 %	27.6 %	30.3 %	15.8 %
LH_2 ICE	13.2 %	23.7 %	25.0 %	31.6 %	6.6 %
Onboard CCS	30.1 %	35.6 %	17.8 %	15.1 %	1.4 %
Biofuels	7.8 %	14.3 %	24.7 %	33.8 %	19.5 %
Batteries	55.8 %	23.4 %	14.3 %	3.9 %	2.6 %

Technology suitability for ferries (over 20,000 GT)

	1	2	3	4	5
Synthetic drop-in fuels	5.6 %	9.7 %	25.0 %	37.5 %	22.2 %
E-fuels	2.7 %	13.7 %	16.4 %	35.6 %	31.5 %
LOHC	20.8 %	20.8 %	31.9 %	15.3 %	11.1 %
Compressed H_2 FC	11.0 %	16.4 %	23.3 %	32.9 %	16.4 %
Compressed H_2 ICE	16.4 %	23.3 %	24.7 %	23.3 %	12.3 %
LH_2	9.7 %	15.3 %	25.0 %	27.8 %	22.2 %
LH_2 ICE	12.5 %	25.0 %	18.1 %	33.3 %	11.1 %
Onboard CCS	42.9 %	32.9 %	14.3 %	7.1 %	2.9 %
Biofuels	11.0 %	11.0 %	26.0 %	30.1 %	21.9 %
Batteries	24.7 %	21.9 %	30.1 %	16.4 %	6.8 %

TABLE 13

Technology suitability for bulk carriers (60,000 – 100,000 DWT)

	1	2	3	4	5
Synthetic drop-in fuels	5.6 %	11.3 %	25.4 %	25.4 %	32.4 %
E-fuels	0.0 %	6.9 %	11.1 %	33.3 %	48.6 %
LOHC	25.4 %	12.7 %	36.6 %	12.7 %	12.7 %
Compressed H_2 FC	26.4 %	23.6 %	26.4 %	5.6 %	18.1 %
Compressed H_2 ICE	30.6 %	23.6 %	19.4 %	15.3 %	11.1 %
LH_2	14.1 %	15.5 %	23.9 %	29.6 %	16.9 %
LH_2 ICE	19.4 %	18.1 %	23.6 %	27.8 %	11.1 %
Onboard CCS	36.2 %	29.0 %	20.3 %	10.1 %	4.3 %
Biofuels	12.5 %	16.7 %	20.8 %	30.6 %	19.4 %
Batteries	77.8 %	9.7 %	6.9 %	4.2 %	1.4 %

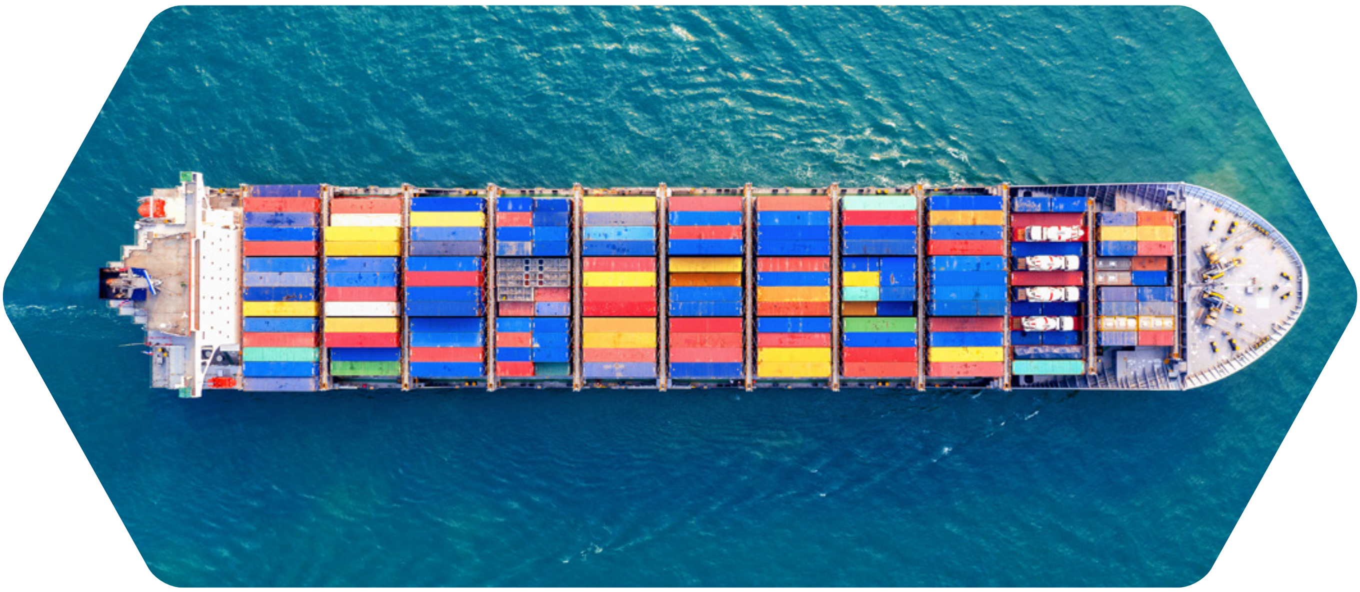
Technology suitability for container ships – feeder vessels (100–2,999 TEU)

	1	2	3	4	5
Synthetic drop-in fuels	5.5 %	13.7 %	28.8 %	17.8 %	34.2 %
E-fuels	1.4 %	6.8 %	10.8 %	29.7 %	51.4 %
LOHC	26.0 %	11.0 %	32.9 %	17.8 %	12.3 %
Compressed H_2 FC	28.4 %	16.2 %	27.0 %	12.2 %	16.2 %
Compressed H_2 ICE	31.1 %	17.6 %	24.3 %	16.2 %	10.8 %
LH_2	12.2 %	16.2 %	25.7 %	27.0 %	18.9 %
LH_2 ICE	20.3 %	12.2 %	29.7 %	25.7 %	12.2 %
Onboard CCS	41.7 %	27.8 %	18.1 %	9.7 %	2.8 %
Biofuels	10.8 %	14.9 %	25.7 %	24.3 %	24.3 %
Batteries	68.9 %	16.2 %	8.1 %	5.4 %	1.4 %

TABLE 13

Technology suitability for large container ships (>3,000 TEU)

	1	2	3	4	5
Synthetic drop-in fuels	2.8 %	9.7 %	25.0 %	25.0 %	37.5 %
E-fuels	1.4 %	6.8 %	5.5 %	27.4 %	58.9 %
LOHC	27.8 %	9.7 %	29.2 %	19.4 %	13.9 %
Compressed H_2 FC	39.7 %	17.8 %	20.5 %	11.0 %	11.0 %
Compressed H_2 ICE	41.1 %	17.8 %	15.1 %	17.8 %	8.2 %
LH_2	15.1 %	9.6 %	34.2 %	23.3 %	17.8 %
LH_2 ICE	19.2 %	8.2 %	31.5 %	30.1 %	11.0 %
Onboard CCS	38.0 %	29.6 %	16.9 %	8.5 %	7.0 %
Biofuels	12.3 %	17.8 %	19.2 %	24.7 %	26.0 %
Batteries	83.6 %	6.8 %	4.1 %	4.1 %	1.4 %



Annex 9 | Bottlenecks and issues for faster deployment of H_2-powered vessels

Ranking determined in range from 0 – **“resolving/not relevant”** to 5 – **“need to be resolved as soon as possible”.**

TABLE 14

Bottlenecks and issues for faster deployment of H_2-powered vessels

	1	2	3	4	5
Manufacturing capacities	1.4 %	14.1 %	28.2 %	28.2 %	28.2 %
Manufacturing materials availability	8.5 %	19.7 %	32.4 %	26.8 %	12.7 %
Market demand	2.8 %	5.6 %	23.9 %	39.4 %	28.2 %
Legislative framework	1.4 %	8.5 %	19.7 %	31.0 %	39.4 %
Powertrain and storage	0.0 %	2.9 %	15.7 %	47.1 %	34.3 %
Lack of retrofitting	1.4 %	15.7 %	27.1 %	42.9 %	12.9 %
Lack of powertrain market	2.9 %	15.7 %	30.0 %	37.1 %	14.3 %
Long-term offtake agreement structure	1.4 %	4.3 %	26.1 %	34.8 %	33.3 %
Safety measures	2.9 %	15.7 %	30.0 %	25.7 %	25.7 %
High CAPEX	0.0 %	1.4 %	18.8 %	20.3 %	59.4 %
High OPEX	1.4 %	8.6 %	12.9 %	24.3 %	52.9 %

Annex 10 | Long-term solutions for hydrogen-powered aircraft: complete results

Ranking determined in range from 1 – **"not suitable"** to 5 – **"perfect fit".**

TABLE 15

Technology suitability for very short-range flights (<500 km)

	Biofuel	HEFA	AtJ	Electricity	E-fuels	H_2 FC	H_2 jet engine
1	10.4 %	16.1 %	9.7 %	19.1 %	1.5 %	7.4 %	10.3 %
2	11.9 %	16.1 %	21.0 %	20.6 %	6.0 %	16.2 %	16.2 %
3	22.4 %	19.4 %	29.0 %	23.5 %	22.4 %	11.8 %	23.5 %
4	28.4 %	27.4 %	24.2 %	20.6 %	32.8 %	36.8 %	27.9 %
5	26.9 %	21.0 %	16.1 %	16.2 %	37.3 %	27.9 %	22.1 %

Technology suitability for short-range flights (500-1,500 km)

	Biofuel	HEFA	AtJ	Electricity	E-fuels	H_2 FC	H_2 jet engine
1	9.0 %	9.5 %	9.4 %	41.5 %	3.0 %	7.5 %	9.0 %
2	9.0 %	14.3 %	17.2 %	30.8 %	3.0 %	13.4 %	10.4 %
3	22.4 %	30.2 %	31.3 %	18.5 %	22.7 %	28.4 %	23.9 %
4	32.8 %	20.6 %	28.1 %	9.2 %	31.8 %	28.4 %	28.4 %
5	26.9 %	25.4 %	14.1 %	0.0 %	39.4 %	22.4 %	28.4 %

Technology suitability for medium-range flights (1,501-4,000 km)

	Biofuel	HEFA	AtJ	Electricity	E-fuels	H_2 FC	H_2 jet engine
1	9.1 %	6.5 %	12.7 %	72.3 %	1.5 %	13.8 %	12.7 %
2	9.1 %	9.7 %	14.3 %	15.4 %	4.6 %	26.2 %	11.1 %
3	16.7 %	35.5 %	31.7 %	9.2 %	15.4 %	20.0 %	27.0 %
4	33.3 %	21.0 %	23.8 %	3.1 %	33.8 %	27.7 %	22.2 %
5	31.8 %	27.4 %	17.5 %	0.0 %	44.6 %	12.3 %	27.0 %

Technology suitability for long-range flights (>4,000 km)

	Biofuel	HEFA	AtJ	Electricity	E-fuels	H_2 FC	H_2 jet engine
1	10.6 %	6.3 %	14.1 %	86.4 %	1.5 %	31.8 %	21.2 %
2	7.6 %	15.9 %	15.6 %	10.6 %	6.1 %	19.7 %	10.6 %
3	15.2 %	20.6 %	28.1 %	3.0 %	10.6 %	16.7 %	12.1 %
4	27.3 %	27.0 %	21.9 %	0.0 %	31.8 %	19.7 %	21.2 %
5	39.4 %	30.2 %	20.3 %	0.0 %	50.0 %	12.1 %	34.8 %

Annex 11 | Bottlenecks and issues for faster deployment of H_2-powered aircraft

Ranking determined in range from 0 – **"resolving/not relevant"** to 5 – **"need to be resolved as soon as possible".**

TABLE 16

Bottlenecks and issues for faster deployment of H_2-powered aircraft

	1	2	3	4	5
Manufacturing capacity	1.6 %	4.7 %	20.3 %	31.3 %	42.2 %
Manufacturing materials availability	9.4 %	12.5 %	29.7 %	26.6 %	21.9 %
Market demand	4.7 %	10.9 %	20.3 %	29.7 %	34.4 %
Legislative framework	0.0 %	4.7 %	26.6 %	31.3 %	37.5 %
Powertrain and storage	0.0 %	4.8 %	27.0 %	27.0 %	41.3 %
Range availability	0.0 %	4.8 %	15.9 %	31.7 %	47.6 %
Fuel storage at the airport	1.6 %	11.1 %	27.0 %	25.4 %	34.9 %
Fuel availability	1.6 %	6.3 %	20.3 %	25.0 %	46.9 %
Long-term offtake agreements	1.6 %	7.9 %	25.4 %	31.7 %	33.3 %
Safety measures	1.6 %	6.3 %	33.3 %	19.0 %	39.7 %
High CAPEX	1.6 %	6.3 %	9.4 %	28.1 %	54.7 %
High OPEX	3.1 %	4.7 %	14.1 %	28.1 %	50.0 %

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