

Leigh Yule

BA Product and Furniture Design

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Mathew Archer

An Investigation into the Viability of Hydrogen as an Alternative Fuel Source for Mainstream Energy Consumption.

Abstract

With the current shift towards clean energy, hydrogen is proving to be a significant alternative for fossil fuels. This essay analyses several considerations of Hydrogen's safety, public beliefs, sustainability issues and efficiency. The aim is to evaluate how hydrogen is a potential energy replacement for worldwide use. Hydrogen fuel cells can have many potential uses including renewable energy storage and powering vehicles. Hydrogen fuels generate power whilst the only emission being produced is water vapor. However, it still has some hurdles, this being, the flammability of hydrogen, complex storage requirements and the cost of equipment. There are also common misconceptions with hydrogen energy due to catastrophic events where people often think of safety, therefore public acceptance is also a critical issue to think about within this essay. Hydrogen is better than electric vehicles for long-distance travel and industrial purposes, but it requires huge infrastructure development and a huge shift to green hydrogen for real sustainability.

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Introduction

The increased demand for an alternate energy source on a global scale has placed a timeframe on finding a solution to the environmental issues caused by fossil fuels. This timeframe is one that has shifted the focus towards renewable energy technologies, therefore creating a big debate between electric fuel and hydrogen technologies on the future of energy consumption. Hydrogen technology has lately gained lots of attention in this transition due to its promise of being clean, flexible, and sustainable. Efficiency, safety, sustainability, and public opinion will be the major factors that this essay will use to evaluate hydrogen's viability as a commonly utilized energy source in the future.

While hydrogen can produce electricity without producing harmful emissions whilst also providing a great deal of flexibility in its uses, these fuel cells certainly sound like a very important alternative to fossil fuels. A key feature of Hydrogen is its ability to store excess energy from renewable sources such as solar and wind to supply industrial energy and powering automobiles. Hydrogen is fast becoming an important factor in the mission for sustainable energy given that international efforts to address climate change are increasing.

The essay raises several critical aspects that are relevant for the analysis of hydrogens application in the future. Flammability and storage conditions make safety an outstanding issue. Public confidence can be gained only when such critical issues related to safety are resolved. Furthermore, various hydrogen generation techniques must be assessed against environmental impacts including grey and green hydrogen which will be discussed further in the essay.

The future of hydrogen is still being developed as technology improves. New methods are being devised in relation to its production, storage, and usage is becoming closer to a brighter future of hydrogen becoming a clean source of energy. Public opinion is still one of the obstacles, due to various past events and common misunderstandings. Effective public communication of the key benefits and safety precautions will be crucial in further deployment of the fuel. The following essay will also present a public survey considering the understanding, knowledge, and opinions that the public have about this technology.

Another important consideration is the efficiency of hydrogen as an energy source. This essay will compare the efficiency of hydrogen with electric vehicles and conventional

combustion engines to better understand the potential benefits and drawbacks of hydrogen. This study, therefore, evaluates hydrogen's contribution to a sustainable energy future based on survey data and comparative analysis. The essay is organized to cover the following main topics: efficiency, sustainability, safety, and public perception. It concludes with some observations about how hydrogen may support global energy changes and whether it is the new emerging technology of the world.

Why We Need Alternatives to Fossil Fuels?

The demand for all sources of energy except for these cleaner ones continues to rise, because energy demand worldwide increases, while prices of fossil fuels are likewise hitting record levels. Coal, oil, and natural gas are the most known types of fossil fuels. They are slowly being used up therefore there is a finite number of this resource and results in substantial environmental degrading as well as air and global warming pollution.

Transportation consumes a lot of petrol and diesel as well as a lot of energy and most greenhouse gases into the atmosphere. According to International Energy Agency, about 25% of the global CO₂ emissions are from transportation sector.

Among these fuels, the cleaner and renewable resources are more vital in combating the environmental effects brought about by the fossil fuels. Hydrogen is different from other fuels in that its production can be based on multiple sources both renewable such as wind, sun, and hydro and those that are non-renewable such as coal and natural gas. Therefore, it reduces air pollution and has more potential in combating global climate change, hydrogen has more recently been investigated as a source of renewable energy (Mónico Muñoz and Ríos Esparza, 2024). Besides, the production of hydrogen by using renewable energy sources, mainly water electrolysis, is gaining momentum as another way of cutting greenhouse gas emissions. Through this process, excess renewable energy can be transformed into hydrogen, which then gets stored and used when demand for energy rises (Guilbert and Vitale, 2021). This is also known as green hydrogen.

What is Hydrogen Energy?

Hydrogen energy is derived from hydrogen, which is the most abundant substance in the universe. In application, there exist two major methods of harnessing it: fuel cells and combustion. These fuel cells are an attractive option for energy conversion as their efficiency is considerably higher compared to the conventional combustion engines (Kojima et al., 2004). The production of hydrogen, especially through methods such as water electrolysis, is vital in ensuring that the hydrogen used by fuel cells is sustainably produced. Electrolysis has the capability to reduce carbon emissions by fabricating high-purity hydrogen whose only by-product is water (Shiva Kumar & Himabindu, 2019).

Hydrogen can be produced in several ways, including:

Electrolysis essentially works by utilizing electrical energy in driving a chemical reaction whereby water is separated into its elemental forms of hydrogen and oxygen. In the case of electrolysis of water, renewable energies will ensure that 'green hydrogen' comes forth, without adding linkages that rely on fossil fuels as sources; hence underlining the fact that decarbonization throughout a value chain of hydrogen does take place (Franco and Giovannini, 2023)

Steam Reforming method: Hydrogen is extracted from methane gas which reacts with steam at 700–1000°C, using a catalyst, to yield the hydrogen and carbon monoxide, with carbon dioxide as a byproduct (Nogales-Delgado, et al., 2023). This method is what is called grey hydrogen.

There are several crucial steps and factors that one considers in developing hydrogen through steam biomass gasification. Steam gasification is a process in which biomass is cooked to high temperatures, usually below 850°C, and combines with superheated steam to create synthesis gas, or syngas, which is mainly made up of hydrogen (H₂), carbon monoxide (CO), and other hydrocarbons (Andrew et al., 2016).

Hydrogen, in the case of backup power, could serve as an asset in storing energy that can easily be transformed back into electricity. This capability is very important for industrial companies and energy-intensive industries, whereby hydrogen could serve as a buffer against supply and demand fluctuations in energy (Kalchschmid et al., 2023).

How is Hydrogen Energy Currently Used and How it has been successful?

Hydrogen could reach cost competitiveness in 2025 in transport, if sector-specific CO₂ levies are levied on the German economy, supply chain studies have stated (Cerniauskas et al., 2019). Hydrogen Fuel Cell technology could be the substitute for fossil fuel in public transport and commercial fleet buses and lorries. In an effort to encourage this further, the adoption of hydrogen vehicles, infrastructure needs to be built specifically for hydrogen refuelling (Dissanayake et al., 2020).

At the same time, with a strategic roadmap for the development of a hydrogen society, Japan has made remarkable progress in hydrogen technology. The construction of hydrogen stations and a mass supply chain for hydrogen are firmly focused on in the road map, which is already operational to improve energy security and reduce CO₂ emissions from the transport sector (Iida and Sakata, 2019).

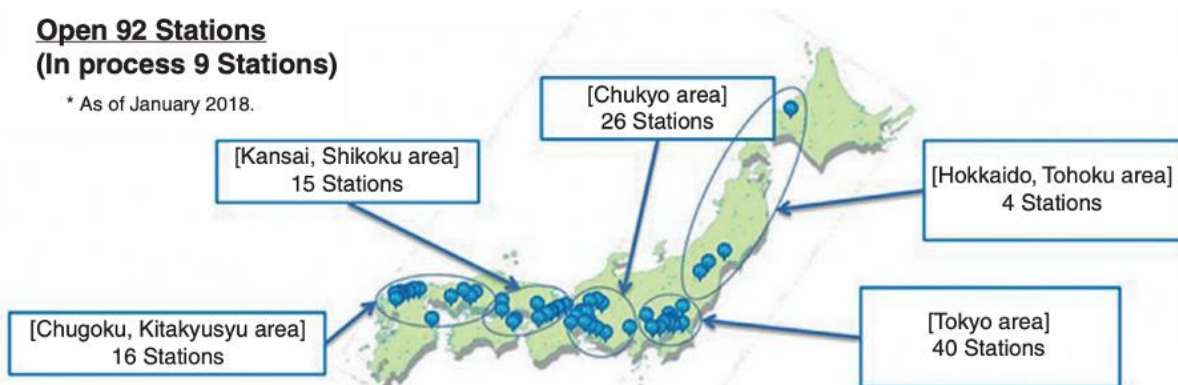


Figure 1, (Iida & Sakata, 2019).

Currently, fuel cell passenger vehicles are manufactured only by Toyota and Hyundai-the two vehicle names being the Hyundai Nexo and the Toyota Mirai. Both the companies are currently working on the technology, focusing on reducing the size, weight, and cost of fuel cell systems, while simultaneously increasing power output. These developments will go a long way in popularizing hydrogen and developing a supportive refuelling infrastructure for fuel cell vehicles (Greimel, 2022).

Germany aims to have carbon-neutral electricity production by 2045, which is an ambitious target. Hydrogen could be the major contributor to such an energy transformation process

that will help the nation reach its goals. Germany, however, is prepared for hydrogen fuel cells on a grand scale, addressing the intermittency issue of renewably sourced energy. It is being aimed to counter both the supply-demand balance and efficiently cater to the energy shortage caused by the fluctuating nature of renewable electricity (Dominic et al., 2024).

The integration of renewable energy by Germany and Japan may be eased through various factors that highlight the potential of both countries to alter their energy systems. Both countries' energy transitions tend to be heading towards hydrogen implementation because of the entry of many firms into the energy market (Wagner et al., 2021).

Challenges and Limitations of Hydrogen Energy

With its potential, there are several obstacles preventing hydrogen energy from being widely used:

The manufacturing process for hydrogen fuel has complex financial effects depending on the method, hence presenting challenges in widespread adoption. Three major trends were found when researching the cost trends of hydrogen generation using a variety of techniques from 1979 to 2020. Production prices for grey hydrogen, historically the most common type, increased until 2015, from which they started to decrease. Since 2015, the cost of renewable electrolysis has been steadily going down, always being the most expensive technique. However, infrastructural problems and a high initial cost continue to block full-scale deployment of this technology. Biomass hydrogen, which was moderately cost-effective up until 2015, but has emerged as the most expensive production route in the recent years. as previously mentioned, the variability in costs and the scale-up challenges bring forth with sharp focus the challenge of producing hydrogen on a cost competitive basis with other energy carriers. However, the potential of CO₂ emission reduction is relatively high for both biomass hydrogen and renewable electrolysis, with the latter having higher potential due to the continually falling production costs.

Distribution and Storage: Hydrogen is to be stored in large amounts or at high pressure due to its low volumetric energy density. The main issue is that the storage aspect is highly problematic regarding transportation. Many studies have noted how the lack of proper refuelling infrastructure is a key obstacle for the adoption of hydrogen vehicles (Greene et

al., 2020). A hydrogen infrastructure around the world will require huge investments in pipes, distribution networks, and filling stations

While being a clean process for hydrogen production, it is relatively less efficient compared to alternatives such as the direct use of fossil fuel or battery storage. The energy losses in the production of hydrogen, and mainly from water electrolysis, are significantly related to inefficiencies intrinsic to the electrolyzers, which add up at each step of the process (Rolo et al., 2024).

Public Perception and Safety Concerns: While the safety measures have been enhanced, there is every reason to raise well-grounded safety and storage concerns with highly pressurised hydrogen regarding fuel cell cars and refuelling facilities. For hydrogen to find its wider application as an energy source, major safety concerns about its extreme flammability and the possible explosive reactions need to be resolved (LaFleur, 2019)

The Safety Challenges of Hydrogen as a Fuel Source

Storage and Transportation Risks

One of the biggest obstacles to the adoption of hydrogen has been ensuring that it is safely stored and transported. Containment is extremely difficult by the small molecular size and flammability of hydrogen. Ever since the historical tragedy of the Hindenburg, there has been a fear of hydrogen explosions, which makes it quite essential to have a thorough understanding of hydrogen flammability to provide safe energy systems (Jeon and Kim, 2020). Hydrogen indeed can seep in through minute cracks, the probability of structural failure increased and hence caused the material to become brittle (Somerday & San Marchi, 2014). One of the popular ways of achieving the needed energy density for transportation applications is by storing hydrogen at high pressure, such as 700 bar or 10,000 psi. (Shin and Ha, 2023). There are, however, a number of serious risks in this, since any structural failure of the storage would lead to the catastrophic release of hydrogen, creating very serious safety concerns. Similarly, liquid hydrogen transportation requires maintaining cryogenic temperature below -253°C ; this, in turn, will require specialised equipment for the

maintenance of stability and safety during the handling and transportation process (Wang et al., 2021).

Risks During Refuelling

As a result, the necessary measures have been taken at Hydrogen refuelling stations, which reduce risks associated with it. The nozzles of Hydrogen measure flow rate, hence ensuring safety in operation which minimizes risks that may cause Hydrogen leaks (Genovese et al., 2024). Design features such as blast walls and flame arrestors are being incorporated more into modern station design as hydrogen is more prone to spontaneous ignition compared with the traditional fuels, making it more hazardous. However, these make hydrogen much safer but also significantly increase the cost of implementation and operation.

Safety in Hydrogen Fuel Cell Vehicles

Hydrogen fuel cell vehicles are safe. Safety-specific issues have been pointed out in hydrogen vehicles, especially as regards the high-pressure hydrogen storage needing to be able to withstand all forms of physical pressures including collision (Park et al., 2023). It requires research on more tough materials and developing more safety considerations in the handling of hydrogen in transport and storage. It must be ensured that the structural integrity of these tanks is maintained to avoid catastrophic failures external or internal pressure (Magliano et al., 2024). Hydrogen vehicles, unlike electric vehicles, face distinct safety concerns. While electric vehicle batteries can sometimes overheat and burn, hydrogen has severe hazards with its flammability and quick dispersal. While these risks have mostly been reduced due to heavy safety regulations and improvements in how the vehicles are designed, the limited deployment of FCV compared to EV means a limited safety data and feeds into scepticism by the public.

Public Perception and Knowledge of Hydrogen Safety

Insights from Crawley: Hydrogen Bus Experience

Public opinion is very crucial in considering hydrogen as a substitute fuel source. Crawley, where 34 hydrogen-powered buses are put into practice, can offer the insightful view of the

residents and drivers. The response from a local bus driver stated that while the buses are appreciated for their environmental benefits, people were concerned with safety. Strong measures such as automated leak detection systems and hydrogen tanks reinforced with strong materials are hardly known by the public.

From the results of the survey, Safety is the most frequent concern related to hydrogen energy. Despite such concerns an astonishing 73.3% of those surveyed were optimistic about its future, even though many said they knew very little about the technology. This would suggest that direct experiences with hydrogen technologies, like refuelling or riding a hydrogen-powered bus, strongly improve trust and acceptance. More exposure to these technologies for people could improve their perception of safety and, therefore, help support broader use.

Vehicle Design Innovations

Hydrogen-powered cars have also considerably improved on safety issues thanks to critical design. Hydrogen storage tanks in modern fuel cell vehicles come with multi-layered ability to survive severe shocks that include high pressure. More dependable are additional automated safety measures in the form of emergency shut-off valves and leak detection sensors. But comfort and ease are just as crucial to the success of hydrogen-powered vehicles as their safety. Innovations that would further promote its use include ease of re-fuelling interfaces and small storage designs. Stronger composite tanks and other improvements in materials ensure hydrogen is safely stored and carried at high pressure. Innovations in better station design with automation and safety, such as leak detection systems, improve efficiency and dependability. These tend to build public trust of hydrogen technology while further enhancing public safety. Hydrogen will finally only succeed as a clean source of energy if refuelling stations, besides becoming safer, are more accessible.

The current need for fuel types to change is gradually increasing. With current alternatives to convectional fossil fuels, hydrogen is becoming increasingly apparent as an environmentally friendly competitor. Hydrogen is progressively showing its potential in becoming the new cleaner and greener fuel type. However, this does not come with its own issues in proving its viability due to its technical, economic and social challenges. This survey aimed at exploring the public's views, challenges and prospects. This survey was to discover public views, these

are vital to understanding the acceptance and feasibility of hydrogen as an alternative fuel. The identification of barriers such as safety issues that would have been hard to identify through articles and academic references. A good number of the participants are from Crawley, The Participants being from Crawley provides real-life insights, as residents are directly exposed to hydrogen buses. Their experiences highlight practical benefits and challenges, hence offering valuable feedback for scaling hydrogen technologies.

Survey Results and Discussion

The first question asked in the hydrogen survey was analysing how familiar the public is in relation to their awareness of hydrogen energy. The findings indicated that many the public are not well informed about this technology with only 26.7% were 'not at all familiar' with the new fuel type, while 46.7% indicated that they were only 'slightly familiar' with Hydrogen. This shows that 7/10 participants have limited knowledge of the subject. However, the level of understanding that participants had did not affect their perception as 73.3% of the participants still viewed hydrogen as a viable option for an electric fuel substitute. Of the participants who said yes to hydrogen being a viable alternative, most were 'slightly familiar' with hydrogen energy. This shows that they had some knowledge in the subject before having this opinion. However, although the majority said yes to hydrogen being an alternative fuel the one participant who said no was 'slightly familiar'. Of the participants who were not sure about hydrogen being a viable alternative, most of them had 'no familiarity at all'.

This difference between knowledge and optimism is a key finding as it can suggest that this technology is seen as an exciting opportunity even though the public does not fully comprehend full knowledge of the fuel type. This survey also highlights the need for better public understanding/education as we discover the misconceptions and lack of understanding that can disrupt widespread adoption, especially in such categories like safety and infrastructure issues. When asked about the primary concern about hydrogen technology, over half of the respondents cited 'safety' as their primary concern. The next category of concern was lack of infrastructure, with 20% of respondents citing this as their primary concern. Governments and industry sectors need to invest in public awareness campaigns to clarify hydrogen technology, the benefits and to answer the publics concerns.

A key factor that has been taken from this analysis of hydrogen possibility is essentially from an environmental point of view. From the survey, 66.7% of the participants believe that hydrogen is more eco-friendly compared to electric fuel cells while only 13.3% electric power cells are believed to be greener types of fuel. This over-liking for hydrogen proposes it as a competitor to reduce carbon emissions by reducing the effects of climatic change drastically. This might be because the subjects were familiar with hydrogen busses, and they could perceive a positive outcome. The positive environmental factors of this fuel technology are significant when it can be made through sustainable methods. One such method is green hydrogen, and this is created by renewable-powered electrolysis and only produces water vapour during production therefore making it a fully zero emission fuel. This makes it especially important in various sectors like the transportation and heavy industry.

A key factor to not is not all hydrogen energy is the same. In fact, a large amount of today's hydrogen energy is 'grey hydrogen' which is produced from fossil fuels, which discredits its usefulness of being sustainable. While 60% of the participants were aware of green hydrogen, 40% was not. This finding is concerning as the growing public support for hydrogen may change if its production is perceived as environmentally harmful. To address this, governments and industries should accelerate the transition to green fuel types and concisely communicate the actions take to phase out fossil fuel production methods.

When asked about the most important factors when evaluating fuel sources, the priorities were ranked in the order of cost; performance and efficiency; environmental sustainability; safety. This shows that although people do have concerns about environmental sustainability, personal cost is priority, and the ability to perform well. If stored properly, hydrogen could be a cost effective, high performing, environmentally sustainable fuel. Currently, the expense of storing hydrogen is expensive. so, this would have to be considered if making it an affordable fuel source. Interestingly, nobody answered 'no' when asked if governments and industries should prioritize hydrogen over electric vehicles in the future. 53 % said yes, whereas the other respondents said 'maybe'. The people who said 'maybe' were the same as the people who were unsure if hydrogen is a viable alternative to electric fuel cells.

The other two important drawbacks to the use of hydrogen as an alternative fuel are related to the aspects of infrastructure and safety. Flammability and pressure-related hazards were

mentioned by a little over half of respondents in this regard. This is mainly because hydrogen is flammable, and for its storage and transport, highly sophisticated technology is required, coupled with utmost care to avoid any serious disasters. These risks can be minimized during refuelling and in transit with strict safety protocols, and hydrogen storage tanks today are designed to be resistant to harsh conditions. Hydrogen-powered projects involving trains and buses, for example, are experimental projects that can serve as an opportunity to show the safety of the technology in real-life scenarios. These initiatives contribute to scientific progress and public confidence, showing that hydrogen can be used safely and dependably.

Another significant issue is infrastructure. There are few hydrogen refuelling facilities, in contrast to systems of electric vehicle (EV) charging stations. Customers find it challenging to consider hydrogen as a viable alternative due to its limited availability. Despite this, the poll indicated that respondents valued hydrogen's longer driving range (26.7%) and quicker refuelling times (40%) in comparison to EVs. These advantages make hydrogen most suitable for long-distance transport and fleets for commercial purposes where time and range become major factors. For hydrogen to become feasible in the broad energy landscape, some serious infrastructural investment is in order (Weinert and Lipman, 2006). In developing a network of hydrogen refuelling stations-especially for transportation and heavy industry-Governments must be aligned with private investors.

The research also delved into the economic feasibility of hydrogen. The study showed that, from one-third of those interviewed, hydrogen is much too expensive compared to electric batteries and gasoline cars due to high production costs. The costs of renewable energy and electrolysis technology make the generation of green hydrogen expensive to achieve today. With temporary decreases in prices fostered by subsidies and various government incentives, hydrogen may reach some kind of competitive point against conventional sources of fuel. With the development of technology, these costs need to go down. 71.4% of the participants think that governments should invest more in hydrogen than electric vehicles. The public knows well that hydrogen needs financial support to reach its critical mass and become one of the common fuel types.

Over three quarters chose the transportation sector from the survey as having the biggest potential for hydrogen. This could be due to hydrogen being more appealing to vehicles like trucks, buses, ships, and even airplanes whereas batteries fall short of performing the task.

There are indeed cases where it surpasses electric batteries since substantial amounts of energy can be contained within a small structure. Hydrogen, apart from transportation, is being used in industrial operations and for energy storage. It can act as an emergency fuel where it releases energy if it is needed and stores it when supply exceeds demand.

Hydrogen can be a substitute for fossil fuels in those industries, such as the chemical and steelmaking sectors, where emission cuts are needed. Most, according to the survey, were less familiar with the roles of hydrogen beyond transport. That would suggest that more needs to be done to communicate hydrogen's flexibility and the different ways it might underpin a low-carbon energy system.

Results from the survey show that even with the challenges, people are ready to use hydrogen technology: 86.7% mentioned switching to hydrogen if it was as accessible as electricity or petrol, and 73.3% stated that they would drive a hydrogen-powered car. This readiness implies optimism for hydrogen's future, but it also gives insight into how important making hydrogen available and affordable will be. There are several activities that could stimulate such adoption. The improvement of public awareness through campaigns comes first at 40%, closely followed by safety demonstrations in practical applications at 33.3%.

Conclusion

Hydrogen has huge potential as an alternative fuel that could meet some of the critical global energy challenges, especially those concerning greenhouse gas emissions and their role in climate change. The fact that hydrogen can provide energy with water vapor as the only by-product, and its versatility across different sectors, cements hydrogen's position in the transition toward a sustainable energy future. Transportation, heavy industry, and storage all exhibit hydrogen's unique advantages over the incumbents, including but not limited to electric batteries, particularly where a source of high-energy-density, long-range, or fast refuel requirements are in play.

There remain several significant stumbling blocks that still need to be cleared before hydrogen will transition to eventually being a mainstream source of energy. The bottom-line fact relative to production costs for hydrogen is that they are highly cost-prohibitive and form the number one single hurdle toward true, wide-scale adoption. Most of the current

production methods are based on fossil fuel sources, yielding so-called 'grey hydrogen', with a negative impact on the environmental credibility of this energy carrier. Transitioning to green hydrogen requires large-scale investments in renewable energy infrastructure and the development of technologies that can be scaled up economically.

Other major challenges include safety issues, especially about the flammability of hydrogen and the risks in storage and transportation. Hydrogen safety has been continually questioned by historical incidents and lack of public awareness. Technical advancement in multi-layered storage tanks, leak detection systems, and other advanced technologies at refuelling will solve the problems. Public involvement will also be encouraged through open demonstrations of safety and building up trust through education.

This infrastructural limitation further raises questions about hydrogen's feasibility as a source of mainstream fuel. Inadequate refuelling stations and supply chains hurt the competitiveness of hydrogen against electric vehicles and traditional fossil fuels. Major investments in hydrogen refuelling networks will be required, most particularly for long-distance transport and heavy-duty applications. Examples from Japan and Germany show that, with government leadership coupled with that of the private sector, driving the development process will result in an appropriate model that other regions would follow in time.

The survey shows that most results indicate little public awareness about hydrogen technology but simultaneously being optimistic that it is cleaner compared to fossil fuel. The underlined knowledge-perception gap signals the requirement for stronger public education in order to discard some common misconceptions about its impact on the environment, its safety, and infrastructure demands. Fortunately, the greater part of the surveyed group of participants said they would be ready to use hydrogen-powered technologies if available and could be afforded as easily today. This readiness underlines how important it is to reduce production costs and increase the availability of hydrogen to ensure wide diffusion.

Hydrogen is a clean, game-changing energy carrier that promises a plethora of possibilities

to disrupt world energy systems. With huge environmental benefits, versatility in application, and suitability for highly demanding applications, hydrogen will become inevitable in the fight against climate change. Challenges to its mainstream adoption are huge, but not insurmountable. With strategic investments in technology, infrastructure, and public engagement, together with international collaboration and policy support, hydrogen can realize its full potential. If this effort is realized, hydrogen will be the cornerstone of a cleaner, more resilient, and sustainable global energy future.

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