sustainability

MDPI

Concept Paper

Fuel Cell Electric Vehicles (FCEV): Policy Advances to Enhance Commercial Success

Usman Asif and Klaus Schmidt *

Department of Technology, Illinois State University, Normal, IL 61790, USA; uasif@ilstu.edu
* Correspondence: kschmid@ilstu.edu

Abstract: Many initiatives and policies attempt to make our air cleaner by reducing the carbon foot imprint on our planet. Most of the existing and planned initiatives have as their objectives the reduction of carbon dependency and the enhancement of newer or better technologies in the near future. However, numerous policies exist for electric vehicles (EVs), and only some policies address specific issues related to fuel cell electric vehicles (FCEV). The lack of a distinction between the policies for EVs and FCEVs provides obstacles for the advancement of FCEV-related technologies that may otherwise be successful and competitive in the attempt to create a cleaner planet. Unfortunately, the lack of this distinction is not always based on intellectual or scientific evidence. Therefore, governments may need to introduce clearer policy distinctions in order to directly address FCEV-related challenges that may not pertain to other EVs. Unfortunately, lobbyism continues to exist that supports the maintenance of the status quo as new technologies may threaten traditional, less sustainable approaches to provide opportunities for a better environment. This lobbyism has partially succeeded in hindering the advancement of new technologies, partially because the development of new technologies may reduce profit and business opportunities for traditionalists. However, these challenges are slowly overcome as the demand for cleaner air and lower carbon emissions has increased, and a stronger movement toward newer and cleaner technologies has gained momentum. This paper will look at policies that have been either implemented or are in the process of being implemented to address the challenge of overcoming traditional obstacles with respect to the automobile industry. The paper reviewed, synthesized, and discussed policies in the USA, Japan, and the European Union that helped implement new technologies with a focus on FCEVs for larger mass markets. These regions were the focus of this paper because of their particular challenges. South Korea and China were not included in this discussion as these countries already have equal or even more advanced policies and initiatives in place.

Keywords: fuel cell electric vehicles (FCEV); electric vehicles (EV); policy initiatives; battery electric vehicles (BEV)

check for updates

Citation: Asif, U.; Schmidt, K. Fuel Cell Electric Vehicles (FCEV): Policy Advances to Enhance Commercial Success. *Sustainability* **2021**, *13*, 5149. https://doi.org/10.3390/su13095149

Academic Editor: Marc A. Rosen

Received: 5 March 2021
Accepted: 20 April 2021
Published: 4 May 2021

Publisher's Note: MDPI stays neutral with regard to jurisdictional claims in published maps and institutional affiliations.

Copyright: © 2021 by the authors. Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (https://creativecommons.org/licenses/by/4.0/).

1. Background

Fuel cell technology, and specifically fuel cell technology for the automotive sector, have a great potential to compete with their electric or hybrid counterparts in the attempt to reduce carbon emissions. Hydrogen gas, powering the fuel cell, is a clean and versatile energy carrier with zero CO_2 and NO_x emissions. Hydrogen can be stored and transported in a liquid and gas form and is thus very versatile. Hydrogen can also be used in different segments in power generation, public transport, and industry [1]. Specifically, with respect to battery-operated electric vehicles (EVs), hydrogen-powered trucks, buses, cars, and other commercial vehicles have major advantages due to lower energy density and slower charging times.

As of today, however, fuel cell technology has been overshadowed by the rise of hybrid and electric vehicles. One of the largest barriers to the continued deployment of hydrogen technologies in the automotive sector is stringent laws and regulations. Legal

regulations are more complex for fuel cell electric vehicles (FCEVs) than for other technologies. Specifically, there are several legal barriers with respect to the fueling of FCEV. Firstly, inaccurate hydrogen dispensing options and non-standardized safety regulations are major issues in many European countries. For example, Belgium's fuel distribution system must adhere to very specific criteria that are different from its neighboring countries. Germany's fuel dispensing tolerance is very low, and current hydrogen technology is unable to achieve that threshold and, therefore, would require a relaxation of that rule to allow for higher hydrogen fueling tolerances [2]. Nevertheless, current hydrogen fueling technologies across Europe do not fulfill the same criteria and would, therefore, require more intermediate regulations.

The development of a regulatory framework that defines the commercial production of FCEVs would allow this technology to advance to a level to more effectively compete with other technologies. However, without a clear regulatory framework that helps advance FCEVs and reduce cost factors such as filling stations, storage, and transportation cost, all efforts to introduce these vehicles to a larger commercial-scale may be futile.

1.1. Regulation Challenges

One example of a stringent regulation can be found in the UK: the Gas Safety (Management) Regulations (GS(M)R) of 1996. This regulation defined the specifications of the amount of gas that can be safely transported within the existing network. The regulation limited the hydrogen proportion to 0.1 mol%, which implied that if a higher proportion of hydrogen was used in those pipelines it would make the pipes brittle and porous and, therefore, the gas networks as they existed in 1996 could not be used for the transport of hydrogen. This low hydrogen limit for the existing gas infrastructure, however, was mainly due to historical regulations that date back to the 1974 Health and Safety at Work Act. It appears that using this threshold of 0.1 mol% was rather random and oversimplified the realities of hydrogen pipelining. As a matter of fact, no evidence existed if pipes truly become brittle and porous at any level higher than 0.1 mol%. As a result of this dated regulation, and since a higher dosage of hydrogen-mix is required to establish a safe and commercially feasible transportation system, a separate hydrogen infrastructure would have to be built [3]. Furthermore, filling stations would have to be connected with that new network and draw and process this higher hydrogen mix. In order to separate hydrogen from natural gas, the gas stations would need to use a pressure swing absorption to compress the hydrogen gas, store it, and make it available for the fueling of FCEVs. All these specificities would add to the cost of the hydrogen infrastructure.

1.2. Infrastructure Challenges

One obstacle in advancing the use of FCEVs on a global scale is the lack of a global infrastructure through which to distribute fuel to the end-user. While this challenge may not be a direct result of complex policies and regulations for the technology itself, it manifests rather typical infrastructure issues. For example, according to the Hydrogen Delivery Technical Team Roadmap for the United States, the hydrogen pipeline network in operation expands to only 1600 miles nationwide and is almost exclusively used for delivering hydrogen to very large hydrogen clients such as chemical plants and petroleum refineries [4]. Here, a change of regulations relating to the nationwide hydrogen pipeline network would indirectly impact a positive movement toward increasing the overall marketability of FCEVs.

BMW expert Rücker (2020) stated that "As long as the network of refueling stations for hydrogen-powered cars is so thin, the low demand from customers will not allow for profitable mass production of fuel cell vehicles. And as long as there are hardly any hydrogen cars on the roads, the operators will only hesitantly expand their refueling station network" [5]. On the other hand, the Japanese energy group Iwatani has started to establish a network of refueling stations. However, starting the process of establishing a network in Japan is time-consuming and expensive. In Japan, hydrogen is classified as an industrial

gas, and as a result, unlike in many other countries, refueling stations need to comply with very strict safety regulations [6] and rigorous installation requirements.

1.3. Cost Challenges

One additional barrier to the commercialization of the FCEV continues to be the high cost of the technology itself. There is currently no lower-priced fuel cell vehicle available on the market that can compete with electric or combustion engine vehicles because the cost of fuel cell technology and hydrogen cylinders is still very high. However, comparing the Toyota Mirai (a fuel cell electric vehicle) priced at USD 49,500 to a Tesla Model 3 Performance (a battery electric vehicle, BEV), which is priced at USD 52,690, the Toyota Mirai appears to be quite competitive. This is particularly true since the driving ranges between the two vehicles are very similar [7,8]. Nevertheless, expensive fuel cell technology hinders the development of lower-cost models.

Nissan currently offers a battery electric vehicle for approximately USD 31,600, and that price is significantly lower compared to the lowest-price FCEV, the Toyota Mirai, which sells for USD 49,500. This is because the fuel cell technology used in the Toyota Mirai, also known as proton exchange membrane cell, utilizes platinum, a very expensive metal, in the catalyst layer of the actual cell. This platinum catalyst layer accounts for nearly half of the fuel cell cost [9]. This makes the fuel cell stack by far the most expensive component in a fuel cell vehicle accounting for approximately USD 11,000 [10]. Although the cost of the platinum loading of the fuel cells was reduced significantly over the last decade, it is still a very expensive technology and cannot yet be implemented in vehicles in a USD 20,000 to USD 30,000 price range [11].

Table 1 below juxtapositions FCEV-related technology in Japan, the European Union, and the United States.

Table 1. Summary of the fuel cell vehicle status

Countries	Japan	Europe	USA
Typical products available	Toyota Mirai Honda Clarity (leased only)	Toyota Mirai Honda Clarity (leased only) Hyundai Tucson Hyundai Nexo	Toyota Mirai Honda Clarity (leased only) Hyundai Tucson Hyundai Nexo
Application status	575 and 766 Toyota Mirai were sold in Japan in 2017 and 2018, respectively	130 and 160 Toyota Mirai were sold in Europe in 2017 and 2018, respectively	1700 and 1838 Toyota Mirai were sold in USA in 2017 and 2018, respectively
Fuel Cost per Kg	JPY 1100 (USD 9.85) Ref [12]	EUR 9.50 (USD 11.60) Ref [13]	USD 16.51 Ref [14]
Infrastructure (number of Hydrogen refueling stations)	127 (plan to install 160 by fiscal 2021) Ref [15]	177 Ref [15]	43 (At least 30 more in the stage of planning and construction) Ref [16]
Vehicle Cost (Toyota Mirai)	JPY 7.1 million (USD 68,188) Ref [17]	EUR 64,000 (around USD 77,800) Ref [18]	USD 49,500

The above table displays typical products available in each of the regions. At this point, only Toyota, Honda, and Hyundai have products in the three markets under investigation. However, the application's status, namely the number of vehicles sold in those markets, is very low. Unfortunately, newer data was not available at the time of this study. Fuel costs seem to vary tremendously between each of the regions, but in any case, they are way above other fueling options in each of the respective regions. Even though the number of hydrogen fueling stations is constantly increasing, there is still a lack of Hydrogen fueling stations in all regions reviewed.

2. Discussion of Policies and Roadmaps for Hydrogen Vehicles

2.1. Hydrogen Policies for the United States

The United States is the world's largest producer of natural gas and oil and exports natural gas and oil to more than 35 countries. The United States has, therefore, a unique opportunity to reinforce and grow its energy leadership position in the world and create new jobs. As countries around the world look to hydrogen technology to reduce carbon emissions, the competitive and ample domestic supply of hydrogen would enable the United States to export even more fuel to markets around the world [19] (p. 3).

With hydrogen technology, low-carbon electric power resources achieve a better power grid integration. Electrolyzers that produce hydrogen can significantly increase the flexibility for intermittent renewable energy resources when connected to the grid. This flexibility can provide long-term storage solutions that enhance and supplement the use of short-duration battery solutions. With these long-term storage solutions, hydrogen technology may complement other energy sources such as renewable and nuclear power [19] (p. 3).

The transportation industry accounts for one-third of the carbon emissions in the United States. Therefore, industrial FCEVs could improve the overall air quality. FCEVs and battery-electric vehicles (BEVs) are the only zero-emission vehicle (ZEV) solutions in passenger, commercial, and industrial vehicles. Fueling times have become compatible with conventional gasoline or diesel vehicles, and onboard energy storage capacities increased. Therefore, FCEVs can be considered a complement to ZEV technology and provide a quicker transition to meet zero carbon emission standards. This makes the overall driving and maintenance experience for owners and drivers of passenger and commercial FCEVs similar to fueling at a regular gas station. Thus, it makes FCEVs a competitive solution with quick refueling capacities, longer ranges, and lower vehicle maintenance as compared to their internal combustion counterparts [19] (p. 5).

Regarding the cost of ownership, FCEVs could break even with the cost of internal combustion engine vehicles between 2025 and 2030. Additionally, the uptime, the time that a vehicle runs continuously without refueling, would be lower than for internal combustion vehicles. Currently commercially available FCEV forklifts, for example, are more competitive with their BEV counterparts with regards to higher uptimes, quicker refueling times, and reduced maintenance costs. Therefore, FCEV technology for the commercial sector can be a great alternative to BEVs and conventional fuel-powered forklifts [19] (p. 5).

The current legislation and incentive programs for alternative fuel vehicles are quite complex in the United States. The legislations vary from state to state, which adds additional complexity. The Californian legislation appears to be among the most progressive within the USA. A discussion of each states' legislation would exceed the framework of this paper. The following discussion focused on current federal tax credits and incentives provided for alternate fuel vehicles on a federal level, including FCEVs.

2.1.1. Tax Credits for the Alternative Fuel Infrastructure

The Federal Government provided a tax credit for hydrogen fueling stations installed through 31 December 2020. This tax credit included up to 30% of the infrastructure cost but could not exceed USD 30,000. However, permission and inspection fees were not included in these expenses. Nevertheless, for individuals who own multiple fueling stations and install qualified equipment at multiple sites, the tax credit could be applied to each location [20].

2.1.2. Tax Credits for Fuel Cell Motor Vehicles

A tax credit for up to USD 8000 is available for the purchase of qualified non-commercial fuel cell vehicles. Additional tax credits are available for commercially used vehicles, and the credit amounts are based on vehicle weight. Vehicle manufacturers must follow Notice 2008-33 (PDF) to certify to the Internal Revenue Service (IRS) that a vehicle meets certain requirements to claim the fuel cell vehicle credit [21]. This incentive originally

expired on 31 December 2017 and was retroactively extended through 31 December 2020 by Public Law 116-94.

2.1.3. Alternative Fuel Excise Tax Credit

Liquefied hydrogen enjoys a tax incentive of USD 0.50 per gallon that is available when used to fuel and operate an FCEV. The tax credit is based on the gasoline gallon equivalent (GGE) or diesel gallon equivalent (DGE). This incentive originally expired on 31 December 2017 and was retroactively extended through 31 December 2020 by Public Law 116-94 [22].

2.1.4. Improved Energy Technology Loans

The department of energy provides loans up to 100% of the project cost to eligible projects and programs. These projects must help reduce air pollution and carbon emissions by early adoption of technologies like fuel cell vehicles. These loans are not intended for research and development projects [23].

2.1.5. US Hydrogen Roadmap

As mentioned above, these tax credits and incentives are only enacted at a federal level, and each state may have their own policies. The United States government has devised a hydrogen roadmap that will outline a roadmap of legal policies and initiatives that are required to reduce carbon and NO_x emissions by 16% and 36%, respectively [19]. However, tax credits and incentives provided by the Federal Government may not be enough to propel FCEVs for the mass market. California, for example, is one of the states that has moved beyond this roadmap and has advanced the process of implementing the Hydrogen Highway and offers additional rebates and financing on zero-emission vehicles.

The United States does provide incentives and credits related to fuel cell vehicles (see Table 2). The existing roadmap to make hydrogen vehicles more mainstream has been subject to political debate. However, more work remains to be done in order to make policies and incentives not only consistent across the Nation but also become subject to discourse at the federal level.

Table 2. Hydrogen enablers roadmap for the United States [19].

2020–2022	2023–2025	2026–2030	2031 and Beyond
Immediate next steps	Early scale-up	Diversification	Broad rollout
Policy Support			
Dependable, technology-neutral decarbonation goals in more states and at the federal level Public incentives to bridge barriers to the initial market launches, bring a wider range of mature hydrogen solutions to the market, increase public awareness and acceptance, and continue to pilot across applications Hydrogen codes and safety standards, including blending standards, in certain states Policy/regulatory framework to include grid stability mechanisms for long-duration energy storage, including hydrogen Workforce development programs	Policy incentives (state and federal) in early markets to transition from direct support to scalable market-based mechanisms. Spread public incentives bridging barriers to initial market launches beyond pioneer states Regulatory framework for wider implementation of H_2 energy storage Implementation of cross-sectorial decarbonization policy incentives to support distributed energy resources	Transition of policy incentives in fast-following markets from direct support to scalable market-based mechanisms Applications to broaden beyond transport with specific enabling policies in other sectors (such as industry, power)	Reduced/no direct policy support in certain applications when reaching cost parity Robust hydrogen code at federal level

2.2. Hydrogen Policies for Japan

In contrast to the USA, Japan has a different set of challenges as it relies heavily on imports of fossil fuels. Like most other industrialized countries, most of Japan's energy needs are dependent on imports. As currently approximately 94% of Japan's energy needs rely on fossil fuel to meet domestic energy demands, Japan is highly motivated to move more quickly to hydrogen in order to decrease its fossil fuel dependency.

As a result of the 2016 Paris agreement, Japan formulated a plan to curb carbon emissions and reduce global warming. The Japanese government announced a plan to reduce greenhouse gas emissions by 26% by 2030 as compared to 2013. In order to achieve this ambitious goal, a mix of renewable energy, nuclear energy, and fossil fuels was proposed [24]. Japan also aims to reduce carbon emissions by 80% by 2050 [25].

The Japanese government is aggressively promoting hydrogen fuel cell cars and is easing the legal framework to boost incentives and encouraging the use of the FCEV. Prime Minister Shinzo Abe showed his enthusiasm for hydrogen vehicles by suggesting that all the Japanese ministries and agencies should have fuel cell vehicles [26]. Japan has already the highest incentives for fuel cell cars in the world, with some areas in Japan getting incentives of up to JPY 3 million (approximately USD 26,885 for a Toyota Mirai) that has an actual price tag in Japan of about USD 68,000 [27].

As a leader in hydrogen technology, and since the enactment of the Paris agreement, the Japanese Ministry of Economy, Trade, and Industry (METI) published a strategic roadmap for hydrogen and fuel cells. These roadmaps are used to achieve a carbon-free society.

This strategic roadmap is divided into three sections: hydrogen use in mobility, hydrogen supply chain, and other applications for a global hydrogen society. The first two sections explain how hydrogen fuel and vehicle costs are being lowered by implementing specific action items detailed in the roadmap action plan.

2.2.1. Hydrogen Use in Mobility

This first key objective of the action plan aims to reduce high FCEV prices and ultimately narrowing the price gap between FCEVs and hybrid vehicles from JPY 3 million (USD 28,310) to JPY 700,000 (USD 6605) by 2025. This objective will be achieved by transparency and cooperation between all key stakeholders such as government organizations, automobile industries, energy and power companies. The transparency and cooperation will facilitate more innovation in the field that could ultimately help lower the costs for the end-user [28].

The second objective includes developing technology that helps to reduce platinum in fuel cells. High costs of platinum catalysts used inside the hydrogen fuel cells result in a very expensive technology that is not yet commercially very viable [28]. In order to address this challenge, the Japanese Nisshinbo Holdings commercialized the world's first catalyst for fuel cells that does not require platinum in 2017. This technology has the potential to reduce the price of fuel cell vehicles. Based on research by the U.S. Department of Energy, a single fuel-cell vehicle requires USD 3650 in catalyst materials, which accounts for 40 to 45% of the cost of the components. The main reason for this expense is that platinum sells for almost USD 36.35 per gram. Therefore, replacing platinum with a catalyst that costs less than USD 0.01 per gram will dramatically reduce the fuel cell costs [29].

The third objective of Japan's global warming prevention plan focuses on finding ways to reduce the use of carbon fiber in hydrogen cylinders [28].

Japan's Kawatex company developed a carbon fiber reinforced plastic (CFRP) tank to be used for hydrogen stations [30]. This tank weighing about 1 ton is 5 to 6 times lighter than a tank built with conventional materials that can withstand such gas pressures. The company is also building a 60 L tank for hydrogen cars. This tank is built by wrapping CFRP around an aluminum alloy container in order to reinforce it. This technology will help reduce the use of carbon fiber in hydrogen tanks and hence reduce the costs for the tanks [31].

Japan encouraged the purchase of FCEVs to reach a total of 40,000 units by 2020. However, at the time of the publication of this paper, only 4000 FCEV travel on Japan's roads. The new goal is to reach a total of 200,000 units by 2025 and a total of 800,000 units by 2030 [32]. Nevertheless, this ambition seems to be a far reach at this point. Japan further aimed to increase the number of hydrogen stations to 160 by 2020. Yet again, at the time of the publication of this paper, this number has not been reached yet. The goal for FY 2025 is 320. In spite of all challenges, Japan will continue to promote regulatory reform, technological development, and joint, strategic hydrogen station development within the public and private sectors [33].

2.2.2. Hydrogen Supply Chain

Japan's roadmap also includes a long-term initiative to lower hydrogen prices to a level similar to liquefied natural gas by 2030. This goal will be achieved by building a hydrogen supply network and initiating government-level agreements with countries rich in hydrogen resources. The Japan–Australia brown coal to hydrogen project, for example, will help to lower fuel costs by building a supply chain network and thus reduce costs by transporting and storing hydrogen in bulk. This project, also known as HSEC (hydrogen energy supply chain) project, is one of the world's first to establish an integrated supply chain between Australia and Japan [34]. Kawasaki Heavy Industries are currently building the world's first liquefied hydrogen carrier to transport liquid hydrogen from Australia to Japan. This vessel will transport liquefied hydrogen at 1/800 of its original gas-state volume, cooled to −253 °C, safely and in large quantities from Australia to Japan [35].

These and other new technologies, such as storage and transport technologies, will increase the efficiency of hydrogen liquefaction and will scale-up liquified hydrogen storage tanks with high insulation properties, and thus also help reduce costs for the end-user [28].

2.2.3. Other Applications of Fuel Cell Technologies

In order to achieve a hydrogen society, the Japanese government is planning to implement fuel cell technologies for industrial and commercial use. This objective will be attained by the commercialization of hydrogen power generation and by utilizing CO_2-free hydrogen in the future. The action plan discusses the use of stationary fuel cells that are over 55% efficient and have a durability of 90,000 h that can be used as a power source for existing residential housing. The current durability levels of fuel cells are rather limited. Technologies such as stacked fuel cell technologies will help to increase the durability and efficiency of fuel cell units. Stack fuel cells are considered more efficient and consume less space. They achieve higher power density than current fuel cell technologies [28].

As a pioneer in hydrogen energy, Japan is working on a number of ambitious projects to advance the hydrogen society, including the mass commercialization of fuel cell vehicles. The transition into the mass commercialization of fuel cell vehicles will take many more years, but based on the progress Japan has made, it is likely that those goals will be achieved.

2.3. Hydrogen Policies for the European Union

Like Japan, the European Union is committed to decarbonizing energy systems throughout Europe in order to align with the targets defined in the Paris agreement of 2016. The EU is planning to cut carbon emissions by 95% by 2050 [36]. To achieve these goals, the EU requires advancing and implementing hydrogen technologies on a wider scale, including both the commercial and private sectors [37].

In the EU, the transport sector comprises one-third of the total carbon emissions. Decarbonizing the transport industry is, therefore, a vital step to meet the standards of the Paris agreement [37]. In order to facilitate the use of hydrogen and the development of this technology, a total of 25 member states of the EU signed the Hydrogen Initiative even before the EU hydrogen roadmap was initiated.

However, at this point, Europe lacks the infrastructure to support consumer FCEV. There are only 11 passenger car stations in the UK and about 82 in Germany [38,39]. These

numbers have to increase dramatically, but the infrastructure conditions at this point do not facilitate or allow for more popularity of FCEV.

The Hydrogen Roadmap Europe Report predicts that FCEVs could account for 1 in every 22 passenger vehicles and 1 in every 15 light commercial vehicles by the year 2030 [37].

There are numerous benefits for the reduction of carbon emissions if the 2050 hydrogen vision is implemented in the EU. This roadmap can help meet 24% of the energy demand and reduce 15% of NO_x emissions from road transport and will also reduce 560 Mt of CO_2 [37].

The EU hydrogen roadmap report published in early 2019 discusses that countries like Japan, China, and South Korea are aggressively pursuing hydrogen technologies. These countries made significant advances in hydrogen technology as they issued 55% of the fuel cell patents worldwide, whereas the EU only issued 16% of the patents. This discrepancy suggests that the EU does not have an equally strong decarbonization strategy. In response to this deficit, the EU hydrogen roadmap report addresses to take the following overarching steps to achieve the decarbonization goals:

1. Industry and regulators should work together to set clear, long-term objectives to achieve the decarbonization goals across different segments. Their objectives should not just include the end applications like zero-emission vehicles or decarbonization of houses but include infrastructural developments necessary to support and sustain the end applications [37].
2. In order to remain competitive and attract emerging opportunities, the EU should invent hydrogen and fuel cell technologies. This would require alliances with fast accelerating hydrogen technology markets outside the EU like Japan, Korea, and China in order to reduce the market risk. They should also work with the regulators to build a strong home market within the EU [37].
3. In the transport industry, regulators, and legislators should overcome the chicken-and-egg problem by developing a clear roadmap and policies that ensure a definite solution by unlocking proper investment for a hydrogen infrastructure. A roadmap with the goal of developing a basic infrastructure coverage across Europe will ensure that the automobile industries invest and scale up the development of FCEV, which would ultimately lead to overall cost reductions and more choices for the end-users [37].

As a response to the above roadmap, the interest in hydrogen technology increased in 2020. In July of 2020, the EU launched three key significant policy initiatives:

1. The EU Hydrogen Strategy established initial targets for deployment of hydrogen, which will require up to EUR 470 bn by 2050.
2. The European Clean Hydrogen Alliance (ECHA), a government body, works with the leadership of energy giants like Shell, Siemens, Électricité De France (EDF), and Vattenfall, which comprise the ECHA.
3. A large clean technology innovation fund was set up with EUR 1 bn a year that focuses on investments in hydrogen energy.

There are still additional policy details that need further work, but the Hydrogen Strategy targets represented how the European Union's hydrogen roadmap impacted the significance of hydrogen energy and the European Union's mission for a carbon-free future.

As the European Union is gaining momentum towards building a zero-carbon society, more investments are encouraged to expand the fueling infrastructure. Aiming to address these challenges, Fuel Cell and Hydrogen Joint Undertaking (FCH JU) co-founded a number of projects, including:

HyFIVE, a European project including 15 partners who deploy 110 FCEVs from the five global automotive companies, who are leading in their commercialization efforts (BMW, Daimler, HONDA, Hyundai, and Toyota).

H2ME, a project to increase hydrogen mobility with the intent to expand and develop networks of Hydrogen Refueling Stations (HRS) and the fleets of FCEVs, operating on Europe's roads, in order to significantly expand activities in each country and start the creation of a pan-European hydrogen fueling station network.

H2ME2 addresses innovations required to prepare the hydrogen mobility sector for the mass market. The project will perform a large-scale market test of the hydrogen refueling infrastructure; passenger and commercial FCEVs operated in real-world customer applications and demonstrated the system benefits generated by using electrolytic hydrogen solutions in grid operations.

These projects are only a selection of a larger number of initiatives that have added 55 fueling stations across 10 countries in the European Union and have introduced approximately 1600 FCEV on European roads [40].

Lastly, in order to reduce the cost of expensive carbon fiber hydrogen tanks used in FCEV, new and more efficient manufacturing techniques need to be implemented using carbon composite materials that reduce the costs to make them more commercially viable. Project COPERNIC (COst & PERformaNces Improvement for Cgh2 composite tanks), in collaboration with FCH JU developed a novel carbon-fiber composite tank, which can be built using an automated manufacturing process. These tanks are safer as they implement a novel on-tank valve and real-time monitoring of hydrogen pressure and potential leakages using sensors and optical fibers. This project has helped to lower the cost of a hydrogen tank by EUR 12,000, which represents an 80% reduction in previous costs. As the costs of hydrogen fuel tanks continue to decrease, more FCEVs are likely to come to the market [40].

Table 3 provides a summary and policy review across the three markets discussed [31]. The table displays each regions' national strategy, each regions' hydrogen production and distribution plan, the development plans for the infrastructure development within each region, and the existing or planned incentives and support for passenger and commercial vehicles in each region.

Table 3. Summary of Policy Review [31].

	United States	Europe	Japan
National Strategy	In 1990, the US government published the Hydrogen Research, Development, and Demonstration Act, formulating a 5-year plan for hydrogen energy R&D. The United States formed a systematic basket of laws, policies, and scientific research plans to promote hydrogen energy.	In 2003, the 25 EU nations launched the European Research Area project, which included the building of the European hydrogen and fuel cell technology research and development platform. In 2019, Fuel Cells and Hydrogen Joint Undertaking released the Hydrogen Roadmap Europe, which proposed a roadmap for hydrogen energy development towards 2030 and 2050.	Hydrogen was established as the national energy of Japan, and the government committed to making Japan a hydrogen society. In 2014, Japan launched the fourth Strategic Energy Plan and published the Strategic Roadmap for Hydrogen and Fuel Cells, outlining an integrated approach to hydrogen production, storage, transportation, and applications.
Hydrogen Production and Distribution	In 2019, the Department of Energy issued a funding opportunity announcement for up to USD 31 million in funding to advance the H2@Scale concept, including innovative concepts for hydrogen production and integrated production, storage, and fueling H2@Scale pilot system.	Relative high focus on clean production of hydrogen going forward. Hydrogen Roadmap Europe: a transition to a one-third ultra-low carbon hydrogen production by 2030.	Strategic Roadmap for Hydrogen and Fuel Cells: Building up a commercial-based domestic system for efficiently distributing hydrogen by the mid-2020s and fledged operation of manufacturing, transportation, and storage of zero-carbon emission hydrogen by 2040.

Table 3. *Cont.*

	United States	Europe	Japan
Hydrogen Infrastructure	The DoE launched H2USA—a public-private partnership with FCEV OEMs, focusing on advancing hydrogen infrastructure. The California Fuel Cell Partnership outlined targets for 1000 hydrogen refueling stations by 2030.	In 2009, Germany established H2 Mobility investing in the world's first nationwide network of hydrogen filling stations. Hydrogen Roadmap Europe: 3700 hydrogen refueling stations are expected by 2030.	From 2016–2018, the Ministry of Economy, Trade, and Industry provided a budget of approximately USD 88 million on R&D and approximately USD 539 million on construction subsidies of hydrogen fueling stations.
Support for Passenger Vehicles	The US government clarified the leading role of hydrogen energy in transportation transformation in the all-of-the-above Energy Strategy in 2014. The California Fuel Cell Partnership outlined targets for 1,000,000 FCEVs by 2030.	Hydrogen Roadmap Europe: 3.7 million fuel cell passenger vehicles on road by 2030.	Japan's hydrogen fuel cell vehicles are mainly passenger vehicles, starting from R&D by Original Equipment Manufacturers OEMs, which led to the release of the Toyota Mirai in 2014. The target of 800,000 FCEVs by 2030 Hydrogen Strategy 2017.
Support for Commercial Vehicles	In 2018, the California Air Resources Board preliminary awarded USD 41 million for the shore-to-store project, developing 10 Fuel Cell (FC) class 8 drayage trucks.	Hydrogen Roadmap Europe: 500,000 fuel cell Light Commercial Vehicles LCVs, 45,000 fuel cell trucks and buses on road by 2030.	The target of 1200 FC buses and 10,000 forklifts by 2030 Hydrogen Strategy 2017.

Adapted with permission from Deloitte (2020).

3. Conclusions

In this paper, the researchers identified a number of initiatives and policies that attempt to make our air cleaner by reducing the carbon footprint on our planet. Most of these initiatives have as their main objective the reduction of carbon dependency and the enhancement of newer and better technologies in the near future. Some of these policies address fuel cell technology, and specifically fuel cell technology for the automotive sector. The researchers proposed that fuel cell technology has a great potential to compete with its electric or hybrid counterparts in worldwide efforts to reduce carbon emissions.

Three major industrial regions were under investigation: Japan, the European Union, and the United States. Policies tend to overlap to some degree in the different regions but also display some unique challenges based on cultural, political, and societal differences. However, all three regions spent sufficient time and resources to now engage in the betterment of fuel cell technologies on a global scale. The new policies attempt to reduce cost and certainly engage in an increased infrastructure for these technologies, which are considered two of the most predominant obstacles. Even though the three regions were developed through strategic plans actively transforming those into practice for a wider market are still at very different levels, depending on other competing technologies and their local preferences. As was noted, the competition between EVs, FCEVs, and hybrid vehicles continues to be fierce, and it appears that FCEVs still need to be promoted more in some regions to engage a broader portion of the population in the acceptance of this technology.

Further research should be conducted to find ways to make FCEVs even more competitive, more affordable, and, thus, more popular. Additional research could be included to enhance the use of smart cars, as smart car technology can further decrease worldwide carbon emissions. The development and integration of smart cars, connected cities, and the internet of things may play a major role in providing a stronger legal foundation for FCEVs. Research areas related to this particular integration may open new doors for advanced

FCEV technologies and such provide opportunities for additional governmental initiatives and funding.

Nevertheless, the researchers are optimistic and hopeful that FCEV technologies will become more competitive and affordable in the near future as some of the excessive costs have the potential to be reduced, and some public transportation systems around the world already started to implement FCEV technologies in their public transportation systems.

Author Contributions: Conceptualization, U.A. 60%, K.S. 40%; methodology, U.A. 60%, K.S. 40%; validation, U.A. 60%, K.S. 40%; formal analysis, U.A. 60%, K.S. 40%; investigation, U.A. 60%, K.S. 40%; resources, U.A. 60%, K.S. 40%; data curation, U.A. 60%, K.S. 40%; writing—original draft preparation, U.A. 60%, K.S. 40%; writing—review and editing, U.A. 40%, K.S. 60%; visualization, U.A. 60%, K.S. 40%; supervision, U.A. 40%, K.S. 60%; project administration, U.A. 40%, K.S. 60%. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: Data sharing not applicable.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. Luu, K. Can Hydrogen Become Part of the Climate Solution? 29 July 2019. Available online: https://energy.mit.edu/news/can-hydrogen-become-part-of-the-climate-solution/ (accessed on 25 January 2021).
2. Dolci, F.; Thomas, D.; Hilliard, S.; Guerra, C.; Hancke, R.; Ito, H.; Lucchese, P. Incentives and Legal Barriers for Power-to-Hydrogen pathwAys: An International Snapshot. 27 March 2019. Available online: https://www.sciencedirect.com/science/article/pii/S0360319919309693 (accessed on 25 January 2021).
3. Isaac, T. Hydrogen: Deployment Barriers. Available online: https://www.thechemicalengineer.com/features/hydrogen-deployment-barriers/ (accessed on 25 January 2021).
4. Hydrogen Pipelines. Available online: https://www.energy.gov/eere/fuelcells/hydrogen-pipelines (accessed on 25 January 2021).
5. BMW. Hydrogen Cars, Fuel Cells, etc.: What You Need to Know. 22 September 2020. Available online: https://www.bmw.com/en/innovation/how-hydrogen-fuel-cell-cars-work.html (accessed on 25 January 2021).
6. Green Car Reports. All the Challenges for Hydrogen Fuel-Cell Cars Laid Out. 3 April 2017. Available online: https://www.greencarreports.com/news/1109684_all-the-challenges-for-hydrogen-fuel-cell-cars-laid-out (accessed on 25 January 2021).
7. 2021 Toyota Mirai Exterior Specs & Options. Available online: https://www.toyota.com/mirai/features/mileage_estimates/3002 (accessed on 25 January 2021).
8. Design Your Model 3. n.d. Available online: https://www.tesla.com/model3/design#battery (accessed on 25 January 2021).
9. Proietti, E.; Jaouen, F.; Lefèvre, M.; Larouche, N.; Tian, J.; Herranz, J.; Dodelet, J. Iron-Based Cathode Catalyst with Enhanced Power Density in Polymer Electrolyte Membrane Fuel Cells. 2 August 2011. Available online: https://www.nature.com/articles/ncomms1427 (accessed on 25 January 2021).
10. Tajitsu, N.; Shiraki, M. Toyota Plans to Expand Production, Shrink Cost of Hydrogen Fuel Cell Vehicles. 26 July 2018. Available online: https://www.reuters.com/article/us-toyota-hydrogen/toyota-plans-to-expand-production-shrink-cost-of-hydrogen-fuel-cell-vehicles-idUSKBN1KG0Y0 (accessed on 25 January 2021).
11. Litster, S.; McLean, G. PEM Fuel Cell Electrodes. 2 March 2004. Available online: https://www.sciencedirect.com/science/article/abs/pii/S0378775304000631?via%3Dihub (accessed on 25 January 2021).
12. The Korea Herald. [Hydrogen Korea] Japan Paves Way for Hydrogen Future, but Public Unconvinced. 20 March 2019. Available online: http://www.koreaherald.com/view.php?ud=20190320000706 (accessed on 26 January 2021).
13. Deutsche Welle. Driving a Hydrogen-Powered Car in Denmark. 13 June 2019. Available online: https://www.dw.com/en/driving-a-hydrogen-powered-car-in-denmark/a-49172769 (accessed on 26 January 2021).
14. California Fuel Cell Partnership. Cost to Refill. Available online: https://cafcp.org/content/cost-refill (accessed on 26 January 2021).
15. FuelCellsWorks. In 2019: 83 New Hydrogen Refueling Stations Worldwide. 19 February 2020. Available online: https://fuelcellsworks.com/news/in-2019-83-new-hydrogen-refuelling-stations-worldwide/ (accessed on 25 January 2021).
16. U.S. Department of Energy. Hydrogen Fueling Infrastructure Development. Available online: https://afdc.energy.gov/fuels/hydrogen_infrastructure.html (accessed on 25 January 2021).
17. Nikkei Asia. Toyota Rolls Out Latest Mirai Hydrogen Fuel Cell Vehicle. 9 December 2020. Available online: https://asia.nikkei.com/Business/Automobiles/Toyota-rolls-out-latest-Mirai-hydrogen-fuel-cell-vehicle (accessed on 26 January 2021).

18. Automotive News Europe. Toyota Mirai Fuel Cell Sedan Priced to Win EV Buyers. 4 December 2020. Available online: https://europe.autonews.com/latest-launches/toyota-mirai-fuel-cell-sedan-priced-win-ev-buyers (accessed on 26 January 2021).
19. Road Map to a US Hydrogen Economy—Executive Summary. Available online: https://cafcp.org/sites/default/files/Road-map-to-a-US-hydrogen-economy_Executive-Summary.pdf (accessed on 25 January 2021).
20. U.S. Internal Revenue Service. Alternative Fuel Infrastructure Tax Credit. Available online: https://afdc.energy.gov/laws/10513 (accessed on 25 January 2021).
21. U.S. Internal Revenue Service. Fuel Cell Motor Vehicle Tax Credit. Available online: https://afdc.energy.gov/laws/350 (accessed on 25 January 2021).
22. Excise Tax Branch—U.S. Internal Revenue Service Office of Chief Counsel. Alternative Fuel Excise Tax Credit. Available online: https://afdc.energy.gov/laws/319 (accessed on 25 January 2021).
23. Loan Guarantee Program—U.S. Department of Energy. Improved Energy Technology Loans. Available online: https://afdc.energy.gov/laws/392 (accessed on 25 January 2021).
24. Iida, S.; Ko Sakata, K. Hydrogen Technologies and Developments in Japan. *Clean Energy* **2019**, *3*, 105–113. [CrossRef]
25. Sugiyama, M.; Fujimori, S.; Wada, K.; Endo, S.; Fujii, Y.; Komiyama, R.; Shiraki, H. Japan's Long-Term Climate Mitigation Policy: Multi-Model Assessment and Sectoral Challenges. 9 November 2018. Available online: https://www.sciencedirect.com/science/article/pii/S0360544218320814?via%3Dihub (accessed on 25 January 2021).
26. Edelstein, S. Japan Eases Laws, Boosts Incentives for Hydrogen Fuel-Cell Cars. 15 January 2015. Available online: https://www.greencarreports.com/news/1096324_japan-eases-laws-boosts-incentives-for-hydrogen-fuel-cell-cars (accessed on 25 January 2021).
27. Greenwood, M. Japan Sees Big Future in Hydrogen Cars. 8 April 2019. Available online: https://new.engineering.com/story/japan-sees-big-future-in-hydrogen-cars (accessed on 25 January 2021).
28. Japan, Ministry of Economy, Trade and Industry. The Strategic Road Map for Hydrogen and Fuel Cells. 19 March 2019. Available online: https://www.meti.go.jp/english/press/2019/pdf/0312_002a.pdf (accessed on 25 January 2021).
29. Nikkei Asia. Nisshinbo's Platinum-Free Tech Could Mean Cheaper Fuel-Cell Cars. 13 September 2017. Available online: https://asia.nikkei.com/Business/Technology/Nisshinbo-s-platinum-free-tech-could-mean-cheaper-fuel-cell-cars (accessed on 25 January 2021).
30. Wells Advanced Materials (Shanghai) Co., Ltd. Kawatex Develops High-Pressure Hydrogen Tank. Available online: https://www.wellsepoxy.com/en/index.php?m=content&a=newscontent&id=143&catid=65 (accessed on 25 January 2021).
31. Deloitte & Ballard. Fueling the Future of Mobility—Hydrogen and Fuel Cell Solutions for Transportation. 2020. Available online: https://www2.deloitte.com/content/dam/Deloitte/cn/Documents/finance/deloitte-cn-fueling-the-future-of-mobility-en-200101.pdf (accessed on 25 January 2021).
32. Hall, M. Japan's Struggle to Drive down Renewables Costs. 20 August 2020. Available online: https://www.pv-magazine.com/2020/08/20/japans-struggle-to-drive-down-renewables-costs/ (accessed on 25 January 2021).
33. Japan, Ministry of Economy, Trade and Industry. Basic Hydrogen Strategy. 26 December 2017. Available online: https://www.meti.go.jp/english/press/2017/pdf/1226_003a.pdf (accessed on 25 January 2021).
34. Ishikawa, K. Hydrogen Energy Supply Chain from Australia to Japan. 29 August 2019. Available online: https://netl.doe.gov/sites/default/files/netl-file/19CCUSOGT-20190829-Kawasaki-Final.pdf (accessed on 25 January 2021).
35. Kawasaki Heavy Industries, Ltd. News & Events. 11 December 2019. Available online: https://global.kawasaki.com/en/corp/newsroom/news/detail/?f=20191211_3487 (accessed on 25 January 2021).
36. Jong, W.; Honselaar, G.; Cebolla, O.; Institute for Energy and Transport (Joint Research Centre). CEN—CENELEC Sector Forum Energy Management: Working Group Hydrogen: Final Report. 21 December 2015. Available online: https://op.europa.eu/en/publication-detail/-/publication/99f62cea-a877-11e5-b528-01aa75ed71a1 (accessed on 25 January 2021).
37. Fuel Cells and Hydrogen 2 Joint Undertaking. Hydrogen Roadmap Europe: A Sustainable Pathway for the European Energy Transition. 15 February 2019. Available online: https://op.europa.eu/en/publication-detail/-/publication/0817d60d-332f-11e9-8d04-01aa75ed71a1/language-en (accessed on 25 January 2021).
38. Toyota Mirai Infrastructure. 10 November 2020. Available online: https://www.toyota.co.uk/new-cars/new-mirai/infrastructure (accessed on 25 January 2021).
39. H2 MOBILITY Deutschland GmbH & Co.KG. Hydrogen Stations in Germany & Europe. Available online: https://h2.live/en (accessed on 25 January 2021).
40. Fuel Cells and Hydrogen 2 Joint Undertaking. Making an Impact on the Clean Energy Transition. 25 October 2019. Available online: https://www.fch.europa.eu/sites/default/files/FCH%202019.4582-WEB-2.pdf (accessed on 25 January 2021).