MSc Program
Engineering Management

ACADEMY FOR CONTINUING EDUCATION

The Scope and Feasibility of Hydrogen Fuel Cell Vehicles as an Alternative Sustainable Mode of Transport

A Master's Thesis submitted for the degree of
“Master of Science”

supervised by
em.o.Univ.Prof. Dr.techn Dr.h.c.mult. Peter Kopacek

Jens Chenthadiyil BSc

12038047

Vienna, 21.04.2022

Affidavit

I, **JENS CHENTHADIYIL BSC**, hereby declare

1. that I am the sole author of the present Master's Thesis, "THE SCOPE AND FEASIBILITY OF HYDROGEN FUEL CELL VEHICLES AS AN ALTERNATIVE SUSTAINABLE MODE OF TRANSPORT", 85 pages, bound, and that I have not used any source or tool other than those referenced or any other illicit aid or tool, and
2. that I have not prior to this date submitted the topic of this Master's Thesis or parts of it in any form for assessment as an examination paper, either in Austria or abroad.

Vienna, 21.04.2022

Signature

Acknowledgements

I would like to especially thank my thesis supervisor Dr.techn Dr.h.c.mult. Peter Kopacek for his guidance, help, and constant support during the whole research work process.

Appreciation is also extended to the members of TU Wien, who facilitated this process and extended their helping hands all the time.

I also want to say thank you to all my professors, who have shared their wisdom with me and have given me valuable life lessons throughout the last years.

I extend gratitude towards my parents who have always reminded me of what is important in life and thank all my friends and study colleagues for a great time.

A man ought to read just as his inclination leads him; for what he reads as a task will do him little good.

\- *Samuel Johnson*

Table of Contents

		Page
	Table of Contents	I
	Abstract	V
1	**Introduction and Motivation**	**1**
	1.1 Overview	1
	1.2 Introduction to Fuel Cell Technology	1
	1.3 Scope of research	2
	1.4 Significance of Research	2
	1.5 Research Methodology	3
	1.6 Limitations	3
2	**Research Background**	**5**
	2.1 The Emerging Concerns about the Environment	5
	2.2 History	6
	2.3 Policy Framework and future targets	8
	2.4 The Fuel Cell	9
	2.5 Hydrogen as a Source	10
	2.6 Critical Analysis of Electric Vehicles (EVs)	13
	2.7 Summary	15
3	**Current State of Hydrogen Fuel Cell Vehicles**	**17**
	3.1 The Current Role in the Market	17
	3.2 Fuel cell passenger vehicles	17
	3.3 Fuel cell electric buses	18
	3.4 Fuel cell light and medium-duty trucks	18

3.5 Fuel cell heavy duty truck 19

3.6 Fuel cell forklifts 19

3.7 Fuel cell application status in mining trucks 20

3.8 Hydrogen development overview by geography 20

3.8.1 California and ZEV states 21

3.8.2 China 21

3.8.3 Germany 23

3.8.4 Japan 23

3.8.5 South Korea 24

3.9 Statistical Analysis of the Worldwide Development of HFCEVs 24

3.10 Benefits of Hydrogen Fuel Cell Vehicles 29

3.10.1 Availability of Hydrogen 29

3.10.2 Driving range and Power Output 29

3.10.3 Environmental Effects 30

3.11 Challenges Hydrogen 31

3.11.1 Extraction of Hydrogen 31

3.11.2 Cost 32

3.11.3 High Voltage Degradation 32

3.11.4 Infrastructure 33

3.11.5 Issue of Platinum 34

3.12 Life Cycle Assessment 34

3.12.1 H2 production technologies 35

3.12.2 Hydrogen storage system 36

3.12.3 H2 delivery pathways 37

3.12.4 Liquid delivery pathway 38

3.12.5 Hydrogen refueling station 39

3.13 Safety and general hazards 40

3.13.1 Safety Measures 41

3.13.2 Safety in usage 42

3.13.3 Flammability 42

3.13.4 Leakage due to small molecules 43

3.13.5 Safety in refueling 43

3.14 Summary 44

4 Qualitative Research 46

4.1 Scope of the Study 46

4.2 Objective of the Study 46

4.1 Research Methodology 46

4.4 Limitation 47

4.5 The Structure of the Survey 47

4.6 Results and Discussion 49

4.7 Interpretations and Findings 53

4.8 Summary 54

5 The Future of Hydrogen Fuel Cell Vehicles 56

5.1 Challenges for the Future 56

5.1.1 Fuel cost and availability 56

5.1.2 Fuel quality 57

5.1.3 Regulations and Standards 57

5.1.4 Retail Dealer Investments 57

5.1.5 Service Cost and Availability 58

5.1.6 Insurance Cost 58

5.1.7 Competing Technologies 58

5.1.8 Pricing 59

5.1.9 Influence of Other Technologies 59

5.2 Subsidies and Incentives 59

5.3 Recommendations 60

5.3.1 Supply Chain Development 60

5.3.2 Safety supervision 61

5.3.3 Integrate the industrial chain 61

5.3.4 Financial support 61

5.3.5 Research Advancements 61

5.3.6 Establishing a Network of Professionals 62

5.3.7 Improving the Infrastructure 62

5.3.8 Existing Automaker's Interest 63

5.3.9 Societal Approval 64

5.4 Summary 64

6 Conclusion 66

List of References VI

List of Figures XII

List of Tables XIII

List of Abbreviations and Symbols XIV

Abstract

In the face of the world's environmental crises, a movement for sustainable energy sources in the transportation industry has gained traction. As a zero-emission alternative to conventional automobiles, hydrogen fuel cell vehicles (HFCVs) provide a unique mix of advantages. The integration of HFCVs into the automobile sector, on the other hand, is currently behind and has a lot of room for development. It is critical to assess the technology's potential and comprehend the scope and feasibility of HFCVs. This study examines the existing literature to answer these research questions. In addition, statistical studies of global HFCV data were analyzed, as well as a survey to determine the present degree of public awareness and understanding of this Hydrogen technology. According to the research, HFCVs have a lot of potential as part of a forthcoming, sustainable transportation solution. However, infrastructure improvements, as well as additional promotional campaigns, are required to gain customer confidence in the new technology. Governments and major automotive manufacturers must work together to develop tools that will allow them to make the best strategic decisions possible when it comes to improving and integrating HFCVs into the road system.

1 Introduction and Motivation

1.1 Overview

The extent of research on alternative energy sources has increased as a result of recent technological advancements and the growing urgency to safeguard the environment. There has been a revived interest in investing in developing technologies, and new policies and government assistance have made it easier to deploy and disseminate "greener" energy sources.

Automobiles represent significant and urgent difficulties, and over the last decade, quick and continuous progress has been made in the development of low-carbon vehicle technology, with automakers gradually bringing models with greater fuel economy to market. Considering they emit no exhaust emissions, Electric Vehicles (EVs) and Hydrogen Fuel Cell Vehicles (HFCVs) have the potential to be viable alternatives in the future. Since Electric Vehicles (EVs) offer the potential to reduce pollution, there has been a surge of attention in electrifying passenger vehicles, and they have grown increasingly prevalent in recent years (Ahmadi and colleagues, 2020). Electric vehicles (EVs) and Fuel Cell Vehicles (FCVs) are viewed as an important aspect of the future transportation solution, especially since the 1973 oil crisis, alternative fuels such as hydrogen have sparked a lot of attention (Ahmadi and colleagues, 2020).

Technologies are being developed to identify environmentally friendly alternatives in the automobile industry, as the automotive sector contributes a significant amount to pollution concerns. Alternative and sustainable low-carbon vehicle options, such as the Nissan Leaf, Mitsubishi iMiEV battery-electric cars, Toyota Prius, Honda Insight hybrid vehicles, Toyota Highlander FCV fuel cell electric vehicles, and Honda FCX Charity, have been developed and exhibited across the world.

1.2 Introduction to Fuel Cell Technology

The most abundant material in the universe is Hydrogen. Possibly due to this abundance, the value of hydrogen is often overlooked. Hydrogen has indeed occupied a central place in mankind's hunt for energy sources, this time in the form of fuel cell applications, after being employed as an inflammable fuel in the first internal combustion engines and powering flight by airships.

Governments all around the globe have been pursuing measures to facilitate the use of ecologically friendly energy sources for some years. The majority of environmental rules, on the other hand, are now aimed towards increasing the availability of electric vehicles. The fact that HFCV development is still in its initial stages is one of the key reasons for this (Shin, Hwang, and Choi, 2019).

1.3 Scope of research

This research paper investigates how Hydrogen Fuel Cell Vehicles affect the automotive market and the energy sector. It will address the research question, “What is the potential for hydrogen fuel cell vehicles as an alternate mode of transportation?”. Furthermore, these sub-questions will aid in the research paper:” How do Hydrogen Fuel Cell Vehicles compare to existing alternatives like Electric Vehicles?”, “What is the role of Hydrogen in the future of the automotive sector?”. Also, it will be examined the extent of accessibility and infrastructure of Hydrogen Fuel Cell Vehicles is. Lastly, the research aims to understand how Hydrogen Fuel Cell Vehicles can play a role in shaping ordinary people’s perspective on alternative modes of transportation and will conclude whether the overall integration of Hydrogen technology in the automotive sector is a good supplement for a more sustainable and environment-friendly future in the transportation sector.

1.4 Significance of Research

Vehicles are noisy and polluting contributors to Greenhouse Gas Emissions (GHG)., with over 1.4 billion on the road. Climate change has become increasingly visible during the last decade, and it is being given more attention than at any other time in human history (Ajanovic and Haas, 2021) .However, giving up the convenience of a car is not a viable option. As a result, it is critical that alternate modes of transportation be developed and made available to the public necessary (Shelly et al., 2021). Government and public awareness play a critical role in the development of environmentally friendly vehicles.

The major goal of this project is to reflect the present status of alternative drive systems and to learn about all of the challenges surrounding the integration of hydrogen fuel cell cars into today's automotive industry. The purpose of this research study is to demonstrate the significance of hydrogen as an energy source. The purpose of utilizing hydrogen is to eliminate carbon dioxide from the atmosphere and so establish a path to meet environmental goals. In the development of hydrogen fuel cell cars, the government, energy and petroleum companies, and manufacturers all have a role to play (Wu et al., 2021). The goal of this research is to illustrate how far they will travel to make the infrastructure balance right. A better grasp of the present state of the automobile sector can help you see why such large expenditures are necessary.

1.5 Research Methodology

The following paper is a combination of a literature review and supporting empirical research. The first part will contain a systematic literature review mainly based on peer-reviewed articles. Scientific and relevant articles and books were found on the following three databases: EBSCOhost, Science Direct, and SpringerLink. A variety of keywords and different combinations was used to ensure an adequate selection of articles. Examples are “Hydrogen Fuel Cell Vehicles”, “Hydrogen as an alternative energy source” and “Hydrogen in the Automotive sector”. Further, the results were filtered for peer-reviewed articles from 2000. Furthermore, Google Scholar was also searched for matching literature. Consequently, the potential sources were screened and reduced to a remaining list of content-specific articles. Additionally, relevant reports, newspaper articles, and official government websites were used for further reference and to gather a more comprehensive view. The empirical part of this research paper is intended to fill the gap of empirical research in the field and add supporting perspectives to the study's literature. It includes a survey designed to elicit more information on society's perceptions and understanding of hydrogen as a potential alternative. Following chapters will offer a more extensive review of the empirical portion of the study.

1.6 Limitations

As with the majority of studies, the design of the current study is subject to limitations. This section will focus on the limitations of the first part consisting of the literature review as later chapters will cover the specific limitations of the empirical part. The primary limitation to the generalization of the conclusions of this paper is the fact that Hydrogen technology is constantly being developed and that certain statements in this research paper might be outdated. The second limitation is that article and journal accessibility was restricted because the study paper is mostly based on papers that could be accessed via the university's primary databases. The research is also subject to time limitations as the research period was within specific time frames set by the educational institution. Another limitation concerns the lack of previous research on topics like the future role of Hydrogen Vehicles during the Covid-19 pandemic. Notably, the scope and depth of analyses in the paper are compromised on many levels compared to experienced scholars' works.

2 Research Background

2.1 The Emerging Concerns about the Environment

Today, road transport is responsible for a significant and rising percentage of worldwide anthropogenic CO2 emissions. Furthermore, it is nearly reliant on oil-derived fuels, making it very sensitive to oil price fluctuations and supply interruptions. Finally, utilizing oil-derived fuels in internal combustion engines results in hazardous pollutants being released into the atmosphere. All of these concerns must be addressed to improve road transportation. Demand management and encouraging co-modality can assist, but to accomplish the goals of decarbonization, energy security, and urban air quality, alternative transportation fuels and vehicles will be necessary (Shelly et al., 2021). When looking at the link between global energy supply and demand, it is clear that the energy need is increasing day by day, owing to the growing population. Oil and its derivatives, which are part of the principal energy source family, are also becoming more popular. Given that these fuels are used in power plants and transportation, it is evident that the transition to renewable and alternative energy sources must be hastened. Aside from limited reservoirs, it's simple to see why alternative fuel cars are so appealing when environmental issues are taken into account. According to the International Energy Agency (IEA), the transportation industry is responsible for around 30% of worldwide emissions, with on-road vehicle emissions accounting for 70% of this (Tanç et al., 2019).

The transportation sector's growing greenhouse gas (GHG) emissions are becoming a more relevant topic of debate and regulation across the world, notably in Europe. Furthermore, air pollution mitigation is becoming a regulatory priority, particularly in metropolitan areas. More than 80% of the world's urban population is currently subject to air quality levels that are below basic norms. According to the World Health Organization, air pollution is responsible for around 4.2 million premature deaths globally. The transportation sector accounts for around a third of overall energy consumption and 25% of total greenhouse gas emissions in Europe (Ajanovic and Haas, 2021). Road transport, particularly passenger vehicles, is responsible for the majority of these emissions (Ajanovic and Haas, 2021). Cutting emissions of the world energy system is required to combat climate change. As a result, the Paris Agreement set the ambitious target of achieving net zero net greenhouse gas emissions by the second half of the century (Wulf et al., 2018).

A new strategy opposing discovering an alternative to oil and fossil fuels is required. In this context, academic and industrial authorities have paid close attention to energy consumption reduction and the use of renewable and sustainable energy. Overall, an ideal successor should be sustainable, sustainable, functional, and cost-effective while emitting less pollution (Foorginezhad et al., 2021). Various regulations and initiatives have already been adopted, and future objectives have been set, to achieve considerable emission reductions in the transportation sector. Increased usage of energy-efficient and alternative vehicular powertrains, as well as low-carbon fuels, is a primary focus. Hydrogen and fuel cell cars are frequently mentioned as important components in the decarbonization of transportation networks (Ajanovic and Haas, 2021).

Sustainability necessitates significant changes in transportation energy generation and use. Hydrogen is one of a tiny handful of energy carriers capable of meeting the bulk of the world's transportation energy needs while emitting almost little carbon dioxide. Electricity, biofuels, and synthetic liquid fuels are among the others. Hydrogen, like all other sustainable energy sources, has considerable obstacles. Each option has its own set of pros and disadvantages when it comes to achieving success. However, pursuing a portfolio of potential choices increases the chances of making a worldwide transition to sustainable energy (Greene, Ogden, and Lin, 2020). In this academic paper, the focus will be given to the perspectives and the future of Hydrogen compared to other alternatives.

2.2 History

Although hydrogen and fuel cells are frequently seen as futuristic technologies, it is crucial to note that they have a lengthy history (Ajanovic and Haas, 2021). Hydrogen was first recognized as a separate element in 1766 and has been seen as a crucial component of the forthcoming energy system almost since its discovery (Ajanovic and Haas, 2021). Humankind has been taught to use water as a fuel since the 18th century. Water is made up of oxygen and hydrogen atoms, as everyone knows. The electrolysis of water is one of the simplest techniques to separate them. Fuel cells are devices that use a technology that works in the opposite direction of electrolysis. A fuel cell is an electrochemical device that converts hydrogen's chemical energy into electrical and thermal energy (Tanç et al., 2019).

A fuel cell is not a modern phenomenon (Deloitte, 2020).. Its origins may be traced back to 1839 when it was initially devised by William Grove, a Welsh scientist. However, it was during the oil crisis of the 1970s that fuel cell cars first gained international attention. Carmakers from various nations invested varying amounts of time and money creating fuel cell automobiles throughout the following few decades (Deloitte, 2020).

In his novel "The Mysterious Island," published in 1874, French novelist Jules Verne predicted that hydrogen and oxygen will be the energy sources of the long term. According to the scholars Ajanovic and Haas (2021), water electrolysis was first demonstrated around the turn of the nineteenth century. Over 200 years ago, hydrogen was employed as a fuel in one of the internal combustion engines (ICE). Hydrogen has been highlighted as a vital component of the prospective low-carbon energy system on several occasions. There have been several "hydrogen hypes" up to this point, but the truth is that hydrogen is today employed mostly for industrial reasons (Ajanovic and Haas, 2021).

Hydrogen employment in the transportation industry can be overlooked with the roughly 13 000 FCVs on the road. However, hydrogen and fuel cell cars have fresh opportunities. Fuel cell manufacture on a large scale has commenced. From personal electronics to forklift trucks, hydrogen and fuel cells are being marketed in a variety of industries. Furthermore, as the usage of renewable sources (RES) in power generation grows, as does the demand for adaptable and storable energy carriers, hydrogen and fuel cells are gaining favor once again. Since 1975, the hydrogen market has increased by more than thrice (Ajanovic and Haas, 2021).

Toyota released the world's first marketable fuel cell car in 2014, marking the conclusion of years of research and development. Fuel cell cars were no longer considered experimental in the eyes of the public after that and were instead regarded as one of the primary driving innovations and technologies of transportation. Nations such as China, the United States, Japan, and several European countries focused their efforts during the following five on advancing this technology (Deloitte, 2020). Fuel cell applications are currently entering a golden period of progress thanks to a combination of government action, technological innovation, and industrial involvement (Deloitte, 2020).

2.3 Policy Framework and future targets

Climate change and global warming are both global issues driven by carbon emissions. Around 200 nations attended the United Nations Climate Change Conference and signed the Paris Agreement to ensure efficient and sustainable growth of energy, economy, and society (Wulf et al., 2018).. Furthermore, 184 nations representing 97.9% of global carbon emissions filed "National Contribution Commitment" documents to combat climate change.

The legislative framework and future objectives will have a big impact on the future role of hydrogen and fuel cell applications in transportation (Ajanovic and Haas, 2021). However, the policies that have been enacted, the investments that have been made, and the future goals that have been set differ substantially from nation to country. Hydrogen and fuel cell technologies are subject to a small number of direct policies. Different national concerns, such as air quality, global warming, energy policy, and so on, drive public funding for hydrogen and fuel cell cars as well as accompanying infrastructure. There is also a diverse set of regulations that indirectly assist the use of hydrogen and FCVs, such as CO2 emissions standards for new automobiles, ICE vehicle bans, and so on. The absence of legislation, as well as coordinated effort among many stakeholders, is a key impediment to the speedier and wider adoption of hydrogen and FCVs. In addition, technical standards are required, which will enable economies of scale and lower investment risks. In most nations and areas, there are currently insufficient investments in hydrogen and fuel cells. Although the market penetration of alternative vehicles and infrastructure roll-out are inextricably linked, the European Commission's plan for post-2021 CO2 objectives for passenger cars and vans makes no mention of the availability of charging and refueling facilities. However, to reflect commercial realities, Europe's long-term climate goals must be tied to future infrastructure feasibility and consumer acceptability. To understand more about new technologies and boost public acceptability, more research and development initiatives are required. However, having a clear long-term goal and a solid policy framework is most crucial from the perspective of societies (Ajanovic and Haas, 2021).

2.4 The Fuel Cell

A fuel cell is a type of electrochemical reactor that transforms the chemical energy of a fuel and an oxidant into electricity directly. More recently, the term "fuel cell" has almost solely been used to denote a reactor that uses hydrogen as its major energy source. Hydrogen has a lengthy history of being utilized as a form of transportation fuel. More than two centuries ago, hydrogen was employed in the earliest internal combustion engines, which were powered by burning hydrogen rather than gasoline. However, due to safety issues and poor energy density, this did not conclude to be very effective. Instead, contemporary fuel cells use hydrogen as an energy transporter, where it combines with oxygen to produce electricity (Deloitte, 2020). The chemistry between hydrogen and oxygen is astonishingly simple, and it may be expressed by the formula

$$2H2 + O2 = 2\,H2O \tag{1}$$

Hydrogen and oxygen are injected separately into a fuel cell, with hydrogen going to one electrode and oxygen to the other. The electrolyte functions as a filter between the two electrodes, preventing the cell reactants from interacting directly with each other and controlling how the charged ions formed during partial cell reactions are permitted to reach each other. The hydrogen electrode (also known as the anode) of the fuel cell is the first place where hydrogen molecules enter. The hydrogen molecules react with (Deloitte, 2020).

These ions travel through the electrolyte and make contact with oxygen at the second electrode (Deloitte, 2020) . The electrons, on the other hand, are unable to flow through the electrolyte. Rather, they pass into an electrical circuit, which generates the fuel cell system's electricity. The catalyst at the cathode allows hydrogen ions and electrons to bind with oxygen in the air to generate water vapor, the process' only waste. The kind of electrolyte used in fuel cells is commonly classified (Deloitte, 2020).

Due to its low working temperature (50-100°C), quick start time, and simplicity of use of its oxidant, PEM is the most marketed kind today. PEM's properties make it perfect for mobility solutions, which is one of the reasons behind FCEVs' fast growth since the 1990s (Deloitte, 2020).

2.5 Hydrogen as a Source

Hydrogen is regarded as one of the most viable fuels for future usage, owing to its versatility, energy efficiency, minimal pollution, and renewable nature. Hydrogen is gaining remarkable traction throughout the world as a means of achieving a clean, secure, and economical energy future. Due to substantial advances in automotive fuel cell technology over the previous two decades, fuel cell electric cars appear to have the best chance of becoming the first to reach a large-scale deployment in the near future. Since 2006, the anticipated cost of a prototype state-of-the-art platinum-based vehicle fuel cell system has decreased by more than two-thirds. If platinum group metal-free catalysts are used, the cost will drop even more due to higher manufacturing volume and lower catalyst costs. Today, fuel cell electric vehicles are getting closer to being commonplace in the marketplace. By the end of 2019, there were 25,212 fuel cell vehicles on the road throughout the world, and there were 470 hydrogen filling stations around the world, with more on the way (Jack, de Souza, and Kalebaila, 2015).

Overall, fuel cell vehicles produce very little noise and emit very few greenhouse gases. Hydrogen usage is predicted to reach around 45 million tons per year in the near future. Hydrogen is the most prevalent element, and it is found in water and organic molecules as a colorless, odorless, and combustible gas. It is detonable in a confined place due to a broad explosion range, but the likelihood of a hydrogen explosion in an open space is much decreased due to quick diffusion and ascending stems with lower density than air (Foorginezhad et al., 2021). Hydrogen, as a clean renewable energy carrier, has a number of advantages, including no air pollution, zero-carbon effect in use, and the ability to be stored, transported, and used. As a result, it may be used to reduce carbon emissions in the transportation, residential, commercial, and industrial sectors (Foorginezhad et al., 2021). Automobiles with onboard hydrogen (H2) fuel cells may run on hydrogen (H2). Hydrogen fuel cell vehicles (HFCVs) have a substantially greater energy conversion efficiency than gasoline-powered internal combustion engines (ICEVs) and emit no polluting emissions at the exhaust. H2 is a cleaner alternate to gasoline and other petroleum derivatives on a well-to-wheels

(WTW) basis. Furthermore, HFCVs can be refueled in minutes and give a refueling experience equivalent to that of standard gasoline-powered vehicles (Liu et al., 2020).

Hydrogen is an emerging and almost established fuel source for cars. Hydrogen cars have been determined to have a global warming potential three times lower than their alternative technology competitors. The use of hydrogen as a fuel is progressively being explored, and it offers various advantages over BEVs in terms of some of the issues that they face, such as longer driving range and faster refilling periods. Although the number of such cars in Europe increased by more than 1000 percent between 2014 and 2019, they still make up a small part of the entire alternative vehicle fleet, with 1,286 vehicles in 2019. As a result, it would be critical to identify all of the factors influencing the technology's future development. The public's social acceptance of new technology is a crucial component supporting its establishment. The public media currently opposes the use of hydrogen as an alternative transportation technology to BEVs, instead portraying BEVs as the sole sustainable option for the future transportation industry (Apostolou and Welcher, 2021).

Hydrogen-related technologies are nearing commercialization maturity, with costs continuing to reduce due to advancements in both technology and the supply chain (Li and Taghizadeh-Hesary, 2022). According to the US Department of Energy, the cost of a proton exchange membrane electrolyze stack declined by 80% from 2001 to 2011, to roughly USD 400/kW, and was further lowered to USD 200–300/kW in 2015, depending on the production scale (Li and Taghizadeh-Hesary, 2022). Between 2006 and 2017, the cost of a fuel cell stack fell from USD 145/kW to USD 47/kW and is expected to decline to USD 36/kW by 2025 assuming annual output reaches 500,000 units. Hydrogen energy, including green hydrogen, is expected to reach cost parity with conventional energy sources in the long term, say by 2030, in several parts of the world, according to mainstream policy-making institutes and international organizations such as the International Energy Agency (2019) and the International Renewable Energy Agency (2020) (Li and Taghizadeh-Hesary, 2022). As a result, various governments and regions have published their roadmaps for hydrogen energy sectors and infrastructure, planning for the commercialization of hydrogen on a broad scale (Li and Taghizadeh-Hesary, 2022).

While battery electric vehicles (BEVs) provide a direct link between electric utilities and mobility, hydrogen (H2) fuel cell vehicles (FCVs) provide an extra link if H2 is created by electrolysis. Because of the smaller battery size and weight limitations, H2 FCV technology is more adaptable to heavy-duty transportation than BEV technology. Electrolysis using renewable electricity would provide renewable hydrogen for vehicle decarbonization. For decades, the simple beauty of making fuel from sunshine, wind, and water has piqued interest in renewable H2, but cost and scale issues with traditional H2 production through steam methane reforming have hampered commercialization. However, due to the affordability of renewable power, advancements in electrolysis technology, and applications that require relatively local H2 generation and consumption, the viability of renewable H2 can be revisited. The notion of renewable H2 is becoming more commercially viable thanks to advancements in technology, cost, and regulation (Sinha and Brophy, 2021).

The technology and applicable standards of FCVs are rapidly maturing as nations and industries continue to invest in their development. The market for FCVs is expanding, and several car firms are demonstrating new models. The Toyota Mirai FCV, which was designed and manufactured in Japan, first went on sale in 2014 and has now attained the highest degree of commercial readiness. In 2016, Honda began mass manufacturing of the FCV – Fuel Cell vehicle. Hyundai Motor Company debuted mass production FCVs in 2018, allowing it to gain a solid position in the market, with the Hyundai Nexo serving as the flagship model. BAIC Group, Yutong, Changan, GAC Group, and other automobile manufacturers in China have achieved mass manufacturing capabilities for FCVs. As a result, FCVs are seen as the ultimate answer for the future zero-emission transportation industry, and they are ready for global deployment and commercialization (Zhang et al., 2022).

Hydrogen has the potential to play a significant role in the manufacturing and transportation industries, as well as in the generation of power, heat, and energy storage. By turning power to hydrogen, which can be utilized as a transportation fuel and for energy storage in backup power plants, hydrogen may connect energy sectors and offer another possibility in reaching 100 percent sustainable energy systems. According to a current study, in a system with more than 70% intermittent renewable power, 10% or more must be converted to hydrogen. In the not-too-distant future, renewable hydrogen generation will be cost comparable with fossil fuels, thanks to considerable reductions in renewable power and electrolyze prices (Oldenbroek et al., 2021). FCEVs are expected to be widely deployed in the future. The possibilities for FCEV implementation are rather promising. According to projections for the years 2030-2050, demand for hydrogen electric cars will continue to rise. It's because of reduced prices, better energy efficiency, longer range, and a growing number of hydrogen recharging stations. The most ambitious areas in this sector are the United States, particularly California, Japan, and Europe. Furthermore, FCEVs must be adopted by customers. Their adoption is contingent on favorable customer perceptions of the automobiles (Reverdiau et al., 2021).

2.6 Critical Analysis of Electric Vehicles (EVs)

After examining the potential of HFCVs, it's vital to compare Hydrogen technology to one of the market's primary competitors: Electric Vehicles (EVs). Electric vehicles have a number of flaws that raise the possibility of HFCVs becoming a part of the answer for a more sustainable future (Ahmadi et al., 2020)..

Since they generate no particulates, electric cars (EVs) and hydrogen fuel cell electric vehicles (HFCEVs) have the capacity to be viable options in the future. Electric vehicles (EVs) have sparked a lot of interest since they help decrease pollution, and they've grown increasingly widespread in recent years (Ahmadi et al., 2020). EVs, however, are still in the minority compared to conventional vehicles on the road. EVs have several challenges, despite their huge reduction in GHG emissions. There are a number of issues, including the high price of electric cars, battery charging periods, and the environmental ramifications of battery replacement (Ahmadi et al., 2020). EV batteries, on the other hand, only release a modest amount of energy density, limiting their range. Furthermore, a bigger battery pack implies a greater purchase price, reducing EVs' economic viability compared to regular gasoline vehicles. A battery-powered vehicle's range is limited due to the weight accumulating. A battery-powered electric vehicle requires a long time to fully charge, and charging stations are few (Ahmadi et al., 2020).

Considering their emissions potential is reliant on how energy is generated, EVs may not be a feasible alternative to conventional automobiles in terms of the environment.

Electric vehicles (EVs) can nevertheless release greenhouse emissions, depending on the energy mix used to generate power in each country. Electric vehicles that run on renewable energy, for example, release nearly no greenhouse emissions. EVs, on the other hand, will have a nonzero carbon footprint in countries where coal is used to produce electricity. The higher the amount of coal thermal output in the energy mix, the greater the levels of GHG emissions associated with fuel conversion efficiency (Shin, Hwang, and Choi, 2019).

Electric cars have received a lot of attention in the previous decade (EVs). Because there are several types of EVs, their potential for reducing GHG emissions varies greatly. Battery electric vehicles (BEVs) and fuel cell cars are of particular importance for reducing GHG emissions (FCVs). These cars emit zero emissions at the time of use, and if power and hydrogen are supplied from renewable energy sources, overall emissions might be greatly reduced. FCVs, on the other hand, are still considered as a future technology compared to BEVs, which are virtually a mature technology utilized in many nations (Ajanovic and Haas, 2021). Even though the amount of BEVs has increased in recent years, particularly in China, the United States, and the European Union, the technology still has several flaws. Short driving distance, long charging time, expensive investment costs, and restricted infrastructure are the most relevant factors. The most problematic aspect of BEVs is the battery (Ajanovic and Haas, 2021). To expand the driving range of BEVs, more battery capacity is required, which results in increased vehicle weight and, as a result, worse efficiency. The greatest benefit of hydrogen is its tremendous energy density (Ajanovic and Haas, 2021).

In theory, rechargeable electric vehicles might be a viable future option. However, there is one significant issue, or at the very least a challenge: the battery. Battery performance must be enhanced, and prices must be decreased. Large sensitivity, long charging times, low energy density, and thus high weight are the main issues with batteries. There aren't many issues. For example, a vehicle with a range of around 500 km requires a lithium-ion battery system weighing 830 kg in BEVs and 125 kg in FCVs with hydrogen energy storage. In comparison to traditional ICE cars, BEVs and FCVs have a lighter energy storage system. Furthermore, battery manufacture and recycling will be a major concern in the future (Ajanovic and Haas, 2021).

Alternative technologies in the mobility sector, such as electric automobiles, are needed because they emit no direct GHG emissions when compared to current technologies (Apostolou and Welcher, 2021). Although the public is aware of the sustainable option of battery electric vehicles (BEVs), there are still some drawbacks that are preventing their widespread adoption, such as high investment costs, short travel range, limited recharging infrastructure, and fossil fuel-based electricity, which reduce the technology's long-term benefits (Apostolou and Welcher, 2021).. According to the European Alternative Fuels Observatory (EAFO), while the number of BEVs has climbed from a few hundred in 2008 to hundreds of thousands in 2019, the yearly increase rate of new registrations has slowed and appears to have stabilized at about 40-50 percent since 2016. The speed with which BEVs are being integrated into the transportation automobile market is being hampered by the disadvantages that modern BEVs still have as compared to conventional automobiles. BEVs are still more costly than their conventional equivalents from a consumer standpoint, and they have a lower driving range, long recharging periods, and insufficient recharging infrastructure, all of which work against their expansion (Apostolou and Welcher, 2021).

Recent events highlight the urgent need for additional technologies, policies, and measures to meet policymakers' emission reduction targets, such as the slow adoption of battery electric vehicles, the unsolved problem of battery recycling, and the growing disparity between electricity supply and demand due to the increased use of variable renewable energy sources (Ajanovic and Haas, 2021).

2.7 Summary

Road transport now accounts for a considerable and growing portion of global anthropogenic CO2 emissions (Shelly et al., 2021). Demand management and encouraging co-modality can assist, but to accomplish the goals of decarbonization, energy security, and urban air quality, alternative transportation fuels and vehicles will be necessary (Shelly et al., 2021). Recent events highlight the urgent need for additional technologies, policies, and measures to meet policymakers' emission reduction targets, such as the slow adoption of battery electric vehicles, the unsolved problem of battery recycling, and the growing disparity between electricity supply and demand due to the increased use of variable renewable energy sources (Ajanovic and

Haas, 2021). Hydrogen offers a variety of benefits as a clean renewable energy carrier, including minimal air pollution, zero carbon emissions, and the capacity to be stored, transported, and consumed. As a result, it might be utilized to cut carbon emissions from transportation, residential, commercial, and industrial sources (Foorginezhad et al., 2021). A fuel cell, according to Tanç et al. (2019), is an electrochemical device that converts the chemical energy of hydrogen into electrical and heat energy. Hydrogen and fuel cells are being sold in several businesses, from personal gadgets to forklift trucks. The hydrogen market has grown by more than thrice since 1975 (Ajanovic and Haas, 2021). In 2014, Toyota unveiled the world's first commercially viable fuel cell vehicle, marking the culmination of years of research and development. During the next five years, nations such as China, the United States, Japan, and several European countries concentrated their efforts on advancing this technology, technical innovation, and industrial engagement (Deloitte, 2020). Hydrogen-related technologies are approaching market maturity, with costs continuing to fall as technology and the supply chain improve. According to mainstream policy-making institutes and international organizations like the International Energy Agency (2019) and the International Renewable Energy Agency (2019), hydrogen energy, including green hydrogen, is expected to achieve cost parity with conventional energy sources in the long run, say by 2030, in several parts of the world (Ajanovic and Haas, 2021). However, the lack of laws, as well as a concerted effort among numerous stakeholders, is a major hurdle to the adoption of hydrogen and FCVs at a faster and larger scale. Long-term climate targets in Europe, on the other hand, must be linked to future infrastructure feasibility and consumer acceptance to reflect commercial realities. More research and development projects are needed to have a better understanding of emerging technologies and increase public acceptance. However, from the standpoint of societies, having a defined long-term purpose and a robust policy framework is critical (Ajanovic and Haas, 2021).

3 Current State of Hydrogen Fuel Cell Vehicles

3.1 The Current Role in the Market

Due to the scarcity of fuel-cell cars on the road today, only a modest quantity of hydrogen is consumed in the transportation sector. In 2019, over 13 000 FCVs were in use across the world, especially in the United States, Japan, China, and Europe (Ajanovic and Haas, 2021). Neither internal combustion engines nor other forms of electric cars and powertrains are yet competitively competitive with fuel cell automobiles. In contrast to electricity, however, hydrogen has the potential to be utilized in a variety of transportation applications where a longer driving range and larger load capacity are necessary. For trucks, buses, and trains, hydrogen in conjunction with a fuel cell is already being employed in development initiatives and niche markets. Hydrogen fuel cell forklifts are already on the market, with over 25 000 forklifts in operation throughout the world. Due to many demonstration projects, the quantity of fuel cell buses is also expanding. Fuel cell buses are manufactured by more than ten businesses throughout the world. There are now about 500 buses, 400 trucks, and 100 vans in use. At the same time, there is evidence of modest progress in the implementation of hydrogen infrastructure. The countries having the most hydrogen refueling stations (HRS) are Japan, Germany, and the United States. At least a few hydrogen refueling stations may be found in several European nations (Ajanovic and Haas, 2021).

3.2 Fuel cell passenger vehicles

The Toyota Mirai, which debuted in 2014, was the first commercially assembled hydrogen fuel cell passenger vehicle (Deloitte, 2020). However, in the United States, Europe, and Japan, adoption has been restricted to hundreds or low thousands of machines each year (Deloitte, 2020). When compared to conventional automobiles, fuel cell passenger vehicles provide a zero-emission option with comparable usability (Deloitte, 2020). Refueling a typical fuel-cell passenger vehicle takes about 3-5 minutes, and the vehicle can go 250-350 miles on a single tank, which is equivalent to

ICE vehicles (Deloitte, 2020).. Leasing businesses, fleet operators, government organizations, and corporate clients are among the early adopters, with few private users, owing to a lack of extensive hydrogen infrastructure. However, as infrastructure improves, private consumption is anticipated to rise in the future (Deloitte, 2020).

3.3 Fuel cell electric buses

Fuel Cell Electric Buses (FCEBs) are now one of the most popular fuel cell applications. This is due to the fact that the bulk of them are government-run and follow a set of operational procedures (Deloitte, 2020). Buses usually travel on regular, predictable routes, necessitating the usage of few refueling stops. Furthermore, public-sector activities have a substantial impact on bus operators, making it an ideal candidate for the early adoption of fuel cell technology. Furthermore, FCEB serves as a very visible, green-society public transportation effort. However, the broad use of FCEBs faces hurdles. To begin with, hydrogen remains pricey when compared to fossil fuels. Second, while fuel cell systems are generally reliable, technical issues may arise as a result of the technology's relative youth compared to ICEs, resulting in inefficiencies for operators. Maintenance and parts replenishing are also difficulties, however they are likely to be handled as use grows (Deloitte, 2020).

3.4 Fuel cell light and medium-duty trucks

Among the key markets investigated, there is a range of activities around the implementation of fuel cell light and medium-duty vehicles, which provides an intriguing contrast to buses because most of these distributions are privately run. Fuel cell technology is viewed as a feasible choice for intra-city and inter-city logistics for a variety of reasons (Deloitte, 2020). Fuel cell trucks generally have a range of more than 150 kilometers, allowing them to handle the majority of intra- and inter-city deliveries. Second, fuel cell trucks can fulfill more stringent environmental and noise requirements in urban areas, prompting the government and fleet providers to speed up their adoption. Finally, as compared to BEVs, FCEVs have relatively quick refueling durations, which considerably enhances a logistics fleet's operational efficiency. Fuel cell technology is a viable technique to cut emissions since freight transport contributes to a considerable fraction of overall traffic flow in metropolitan areas (e.g., 8-15 percent in Europe). The use of fuel cell light and medium trucks in inner-city and inter-city logistics is likely to rise in the near future, particularly in China, where commercial infrastructure development is moving at a rapid rate (Deloitte, 2020).

3.5 Fuel cell heavy-duty truck

Heavy-duty trucks are seen as a viable area for developing zero-emission cars due to their significant pollution and environmental damage. Fuel cell heavy-duty vehicles are trailing behind other applications in terms of development. The majority of major OEMs are still in R&D, and just a few devices have been released or are being evaluated. A combination of high vehicle costs, high hydrogen costs, and inadequate recharging infrastructure has slowed the advancement of fuel cell heavy-duty trucks (Deloitte, 2020). On the plus side, compared to battery electric vehicles, fuel cell heavy-duty trucks may offer faster refilling times, which is important for fleets to decrease downtime in their regular operations. FC heavy-duty vehicles can also go greater distances than battery-electric trucks with comparable specs. Fuel cell technology is maturing and becoming more suited to heavy-duty applications. In the end, a fuel cell heavy-duty truck may offer a range and refilling time comparable to conventional vehicles while still emitting zero pollutants. This means that, in the long run, fuel cell heavy-duty trucks have a good chance of displacing diesel and battery electric heavy-duty trucks (Deloitte, 2020).

3.6 Fuel cell forklifts

Forklifts are a frontier application of fuel cell technology. Firstly, forklifts have advantages over other vehicle types in terms of lower technology requirements and infrastructures. The forklift's maximum output power is only one-tenth that of passenger vehicles 50 (Deloitte, 2020). Furthermore, because forklifts are mostly used in small spaces like warehouses, just a few hydrogen recharging stations are necessary. Finally, FC forklifts provide a number of advantages over other forklift models (Deloitte, 2020). The voltage of traditional electric batteries diminishes as they deplete, slowing forklifts over time and lowering output (Deloitte, 2020). The speed of electric forklifts declines by 14% on average in the second half of an eight-hour shift 158, whereas fuel-cell forklifts may maintain a constant "pick rate" (Deloitte, 2020). Finally, because FC vehicles emit no pollutants, forklifts are appropriate for use in enclosed warehouses in industries such as food and beverage 50 (Deloitte, 2020). FC forklifts are in a commercial stage, especially in the US, where FC forklift ownership is over 25,00042 (Deloitte, 2020). In China, the use of FC forklifts is still limited, but a number of enterprises have begun to work on related vehicle development, which has been aided by district government rules (Deloitte, 2020).

3.7 Fuel cell application status in mining trucks

Fuel cell mining trucks are progressively gaining notice as a viable zero-emission solution among mining businesses experiencing severe decarbonization issues. Fuel cell mining equipment has numerous benefits over traditional diesel units and battery electric vehicles. It could theoretically accomplish the same mobility, power, and safety performance as a diesel car, while also being cleaner than a battery vehicle and charging in less time for longer distances. Unlike diesel engines, fuel cell mining equipment does not produce dangerous pollutants for miners working underground. However, there are now only a few FC mining truck products on the market and no significant demonstration deployment, showing that FC mining truck development is still in its early stages. The FC mining truck is being developed by a number of businesses. In China, for example, the Weichai Group collaborated with many industry partners in 2018 to produce 200-ton FC mining trucks. Anglo American is now also developing innovative mining technology in the United States, such as the FC mining truck. To develop the use of the FC mining truck, further technological research and government backing are necessary (Deloitte, 2020).

3.8 Hydrogen development overview by geography

The initial research and implementation phases of fuel cell technology, like other technologies, are primarily reliant on government regulations and incentives. Governments in China, the United States, Europe, and Japan have all supported the growth of the fuel cell sector to varying degrees and for varied reasons, spending extensively in core technological research and developing subsidy programs and medium/long-term strategic plans. Insights into the growth of hydrogen and fuel cells in each nation may be gained by evaluating government policies as well as industry development in each country. A overview of each country's policy priorities is below the article, which will be examined in greater depth in the sections that follow (Deloitte, 2020).

3.8.1 California and ZEV states

California was the first state to establish a sustainable retail market for FCVs, and it has since adopted a multi-faceted plan to boost FCV sales and the construction of refueling stations that has been copied by states in the Northeast. On the vehicle side, the plan mandates that automakers sell Zero-Emission Vehicles (ZEVs), both FCVs and BEVs, helps to add a state subsidy to the federal tax credit for FCV purchases, establishes FCV sales targets in collaboration with automakers, and promotes FCVs through public education and demonstrations. Supporting policies for hydrogen infrastructure include a low-carbon fuels standard that offers fuel providers credits for low-carbon hydrogen, as well as a provision that at least 33% of hydrogen supplied for cars be produced from renewable energy. Construction incentives and service & maintenance subsidies encourage the deployment of refueling stations. A master strategy for deploying stations coordinates site selection and architectural choices. The state collaborates with local governments to update hydrogen station norms and standards and to integrate lessons learned from previous projects. Simultaneously, the state funds research to assist its market development initiatives and has created tools to aid decision-making, such as evaluating refueling station economics and how they may alter over time as the market matures. The station deployment approach is based on the above-mentioned clustering method, as well as a network of "destination" stations and stations along heavily trafficked routes. Station capacity is provided much in surplus of current demand; current station capacity is around three times current demand. According to California's plan, 26,900 FCVs and 64 stations will be available by 2022, 48,000 FCVs and 200 stations will be available by 2025, and 1 million FCVs and 1000 stations will be available by 2030 (Greene, Ogden, and Lin, 2020).

3.8.2 China

Hydrogen vehicles, such as delivery trucks and buses, are encouraged in China as part of the New Energy Vehicles plan (which also includes PHEV and BEV), which is driven by governmental goals related to energy security, greenhouse gas abatement, and air quality. Both FCVs and hydrogen infrastructures are subsidized to a large extent. Hydrogen is being evaluated not only as car fuel but also as an energy storage technology that will allow large-scale centralized renewable electricity facilities to operate more efficiently. Fuel cell technology has advanced significantly in China, and experts believe that mature fuel cell engine systems will be available by 2025. The Energy Saving and New Energy Vehicle Technological Roadmap, released by the Chinese Society of Automotive Engineers in 2016, outlined technology, cost, and implementation targets for FCV and refueling infrastructure. It advocates for a million on-road FCVs by 2030, as well as the use of a combination of FCVs and BEVs to attain 100 percent zero-emission cars by 2050. According to the proposal, 5000 FCVs will be sold by 2020, 50,000 by 2025, and one million by 2030. As of January 2020, the 2020 objective had been met, with a total output of 5500 FCVs. The China Hydrogen Alliance issued the White Paper on China Hydrogen and Fuel Cell Industry in 2019, advocating for somewhat more aggressive targets: yearly production of 1.3 million FCVs between 2026 and 2035, and 5.2 million between 2036 and 2050, according to the White Paper. The roadmap plan is planned for 100 stations by the end of 2020, 350 by the end of 2025, and 1000 by the end of 2030, after which the stock of FCVs is expected to quickly rise, from 100,000 by 2030 to one million by 2040. By the end of the year, the amount of hydrogen refueling stations had grown from two to seventeen, with 11 more scheduled for the following year. The majority of stations were distributed at 35 MPa in 2019, however, new guidelines have been devised that allow for discharging at 25, 35, 50, and 70 MPa. The current planning and deployment activities are concentrated in seven metropolitan cluster areas: JingJinYi, Yangtze River Delta, Pearl River Delta, Central China, Northwest China, Southwest China, and Northeast China, as well as the city of Zhang Jia Kou, which is a co-host city for the 2022 Beijing Winter Olympics and the only National Renewable Energy Demonstration Zone designated by China State Couture (Greene, Ogden, and Lin, 2020). 74 fuel cell buses provided year-round service along three routes in 2019, with one filling station with a daily capacity of 1500 kg. The city has devised a deployment strategy that would see it become the "Capital of Hydrogen" by 2035. It proposes to run 20 stations and 2000 fuel cell buses fueled by sustainable hydrogen produced by wind and solar energy during the 2022 Winter Olympic Games. The Yangtze River

Delta deployment plan calls for stations to be built along with the existing highway network that connects all of the region's main cities (Greene, Ogden, and Lin, 2020).

3.8.3 Germany

In Germany's recently released national hydrogen strategy, the fuel will be used in all modes of transportation. The bulk of the 114 hydrogen stations in existence in the EU and the UK are in Germany. H2 Mobility GmbH, a combined venture of energy and vehicle industries, is in charge of building a countrywide hydrogen refueling network throughout the country. It receives funding from a number of government agencies. Network planning, permits, purchasing, construction, and operation are all handled by the same business. The first aim is to expand 100 stations ahead of demand in seven primary German urban centers, with stations connected by arterial highways and the Autobahn. In response to the growing number of FCVs, the long-term objective is to add 300 additional stations by the end of 2023. In comparison to gasoline, a crucial component of Germany's implementation strategy is to provide competitive pricing for hydrogen. The cost of distributed hydrogen is around $10 per kilogram, compared to $5 per gallon for gasoline. Despite being a forerunner in the deployment of hydrogen refueling infrastructure, Germany only has 530 fuel cell automobiles, 21 buses, and two trucks in service as of November 2019. The German federal government is providing limited support for the acquisition of FCVs for illustration purposes and is striving to guarantee that proper regulations and standards for FCVs and hydrogen stations are in place. The International Energy Agency created a roadmap that lists the steps thought necessary to effectively deploy hydrogen in the EU, starting with the assumption that large-scale hydrogen is a vital component of the EU's cleaner and more sustainable system (Greene, Ogden, and Lin, 2020).

3.8.4 Japan

Japan's initiatives to co-evolve the FCV and hydrogen markets are part of a bigger drive to establish a "hydrogen society." According to Japan's plan, 40,000 FCVs will be sold by 2020 with 160 stations, 200,000 FCVs by 2025 with 320 stations, and 800,000 FCVs and 900 stations by 2030. Objectives for vehicle and station cost-cutting were also defined to facilitate market expansion. The Japan H2 Mobility organization was formed to design and oversee the installation of hydrogen refueling stations in

Japan. Both stations and FCVs are subsidized by the government, which also finances R&D to meet cost and performance objectives agreed collaboratively with the industry. The government's effort also includes establishing adequate safety rules and standardizing station design requirements. With aspirations to expand nationally by 2025, there were 110 functioning hydrogen stations in the country's four major urban centers (Greene, Ogden, and Lin, 2020).

3.8.5 South Korea

In January 2019, South Korea released its Hydrogen and Fuel Cell Roadmap. Through 2040, the ambitious plan calls for the expansion of hydrogen supply infrastructure, the installation of recharging stations, and the promotion of FCV sales (Greene, Ogden, and Lin, 2020). According to the strategy, South Korea would produce 6.2 million FCVs per year by 2040, with 2.9 million marketed on the local market. On Korean roads, 40,000 buses, 80,000 taxis, and 30,000 trucks are expected to operate. The current FCV subsidy is around half of the retail price, which enabled the sale of 4194 FCVs in 2019. The proposal calls for rapid development of refueling stations, with government subsidies paying half of the cost of a station once again. Thirty hydrogen refueling stations were operational as of September 2019, with another 26 slated to operate later this year or in 2020. By the end of 2022, 310 stations will be operational, with the number increasing to 1200 by 2040. Only 37 stations have opened or are scheduled to open in 2019. All stations distribute hydrogen at a pressure of 70 MPa or a combination of 35 and 70 MPa (Greene, Ogden, and Lin, 2020).

3.9 Statistical Analysis of the Worldwide Development of HFCEVs

This section of the research paper is dedicated to investigating the statistics of the development of Hydrogen in today’s energy and transport sector (International Energy Agency, 2021).

Hydrogen has long been recognized as a possible low-carbon transportation fuel, but it has proven challenging to integrate into the transportation fuel mix (International Energy Agency, 2021). According to the International Energy Agency, the use of Hydrogen in the Automotive and Transport sector has been limited to less than 0.01% of the energy consumed and in 2020 Fuel Cell Electric Vehicles (FCEVs) made up a relatively small percentage of overall vehicle stock (<0.01%) and electric vehicle stock

(0.3 %) (International Energy Agency, 2021). However, as a result of developments in Asia and the United States, the FCEV market is starting to take off and grow in market share (International Energy Agency, 2021).

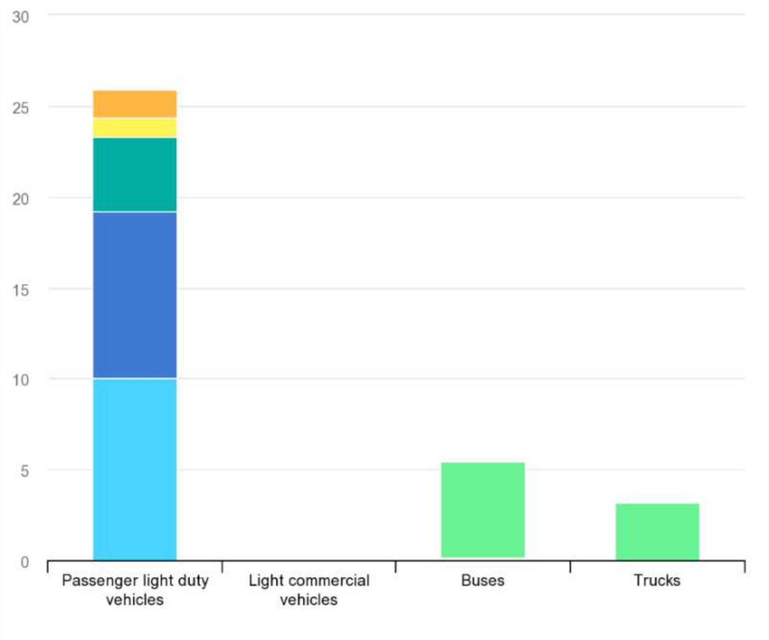

Fig. 1: Fuel cell electric vehicles stock by region and by mode (In 1000) (International Energy Agency, 2021)

The figure above shows a distribution of Fuel Cell Electric Vehicles by region and by transport mode (International Energy Agency, 2021). It can be seen that the implementation into the transport sector is the highest in Passenger light-duty vehicles and is still absent in light commercial vehicles. The integration of buses and trucks is mostly seen in China whereas Korea, the United States, and Japan are leaders in integrating FCEV passenger light-duty vehicles into their transportation sector (International Energy Agency, 2021).

According to data published by the International Energy Agency (2021), there were more than 40 000 FCEVs on the road throughout the world by the end of June 2021. From 2017 through 2020, stocks expanded by an average of 70% each year, but in 2020, stock growth slowed to 40%, and new fuel cell car licenses plummeted 15%, matching the broader car market downturn caused by the Covid-19 epidemic. However, 2021 is likely a new record year, with over 8000 FCEVs sold in the first half of the year with monthly sales in California (759 in March) and Korea reaching new highs (1,265 in April) (International Energy Agency, 2021). The United States had been the leading stockholder since the IEA started keeping track of FCEV stock in 2017, but Korea surpassed it in 2020 because of its strong measures for FCEV adoption, which included subsidies of up to USD 30 000 with the joint backing of national and local governments. Global FCEV deployment has mostly focused on passenger light-duty cars, which represented three-quarters of FCEV stock by the end of 2020, with buses accounting for 15% and commercial vehicles accounting for 10%. The geographical distribution of the various kinds of FCEVs, however, shows some noticeable variances. Since Korea, the United States, and Japan have concentrated their efforts on the deployment of passenger cars, they own 90% of the stock in this sector but just a tiny percentage of the buses and commercial vehicles (International Energy Agency, 2021). Meanwhile, China implemented measures to promote the use of fuel cell buses and commercial vehicles, and today controls the majority of worldwide stock in both categories (93 percent of buses and 99 percent of commercial vehicles in 2020). This trend is anticipated to continue, since China's new fuel cell vehicle subsidy policy, which was established in 2020, intends to boost the FCEV industry's production capacity and emphasizes the use of fuel cells in medium- and heavy-duty commercial vehicles (International Energy Agency, 2021).

Several statements in Europe for 2020 point to further efforts to install fuel cell buses and trucks. Thousands more buses are expected to be deployed in the coming decade by several manufacturers and programs (International Energy Agency, 2021). Hyundai has already delivered 46 heavy-duty trucks to Switzerland, with plans to deploy 1 600 vehicles by 2025, while the Port of Rotterdam and Air Liquide have launched an initiative to deploy 1000 fuel cell trucks by 2025, and a joint call signed by more than 60 industrial partners aims for up to 100 000 trucks by 2030 (International Energy Agency, 2021). The IEA predicts that fuel cell manufacturing may enable a stock of 6 million FCEVs by 2030, meeting about 40% of Net Zero Emissions by 2050 Scenario demands, based on existing and stated capacity.

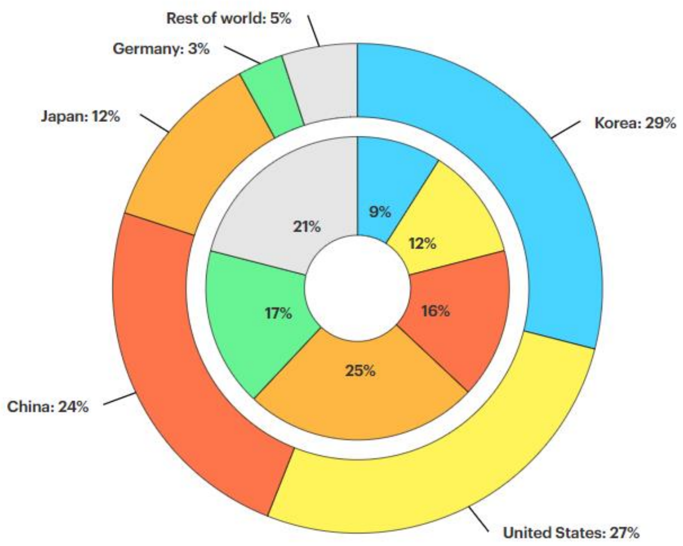

Fig. 2: Fuel cell vehicles and hydrogen refueling station stock by region (International Energy Agency, 2021)

The deployment of fuel cell vehicles should be supported by the construction of supporting infrastructure (International Energy Agency, 2021). The figure above depicts the geographical distribution of Hydrogen refueling stations (2020). The outer circle demonstrates the 34,800 worldwide FCEVs while the inner circle represents the 540 worldwide Hydrogen refueling stations (HRS). More than 540 hydrogen refueling stations were operational throughout the world by the end of 2020, up more than 15% from 2019. With over 140 stations, Japan remained in first place, followed by Germany (90) and China (85). In Japan (+24), China (+24), and Korea (+18), the number of operational stations increased significantly, whilst Germany added just 9 new stations in 2020, falling short of the objective of 100 stations. New applications are gaining popularity in non-road vehicles. Alstom has been a pioneer in Europe's rail industry, having completed a successful 18-month trial of two trains in Germany in 2020, followed by other tests in the Netherlands, Austria, and Italy (International Energy Agency, 2021). As a result, orders have been placed for at least 41 units in Germany and six in Italy, to be delivered between 2021 and 2022, with the first unit arriving in March 2021. Other European companies, including those in France, Germany, Spain, and the United Kingdom, have begun to collaborate with Alstom or are developing and testing their fuel cell train types to replace diesel trains on non-electrified lines.

Countries such as China, Korea, Japan, Canada, and the United States are also engaged in hydrogen fuel cell trains outside of Europe (International Energy Agency, 2021). Hydrogen trams, line-haul, switching locomotives, and passenger trains are all at various phases of research and deployment. In the Net Zero Emissions by 2050 Scenario, hydrogen trains are anticipated to mostly displace diesel lines that are costly to electrify due to poor utilization, accounting for 2% of rail energy consumption by 2030 (International Energy Agency, 2021). The International Marine Organization is working to decarbonize maritime fuels, with hydrogen and ammonia projected to become increasingly significant in the future. Since the early 2000s, hydrogen fuel cells have been shown on a number of coastal and short-distance vessels, although none are now commercially viable. Fuel cell ferries are expected to start functioning commercially in the United States and Norway in 2021. Large oceangoing boats are also showing interest in hydrogen-based fuels, notably ammonia. Major industry players have said that 100% ammonia-fueled maritime engines will be available as early as 2023, with ammonia refit packages for existing boats starting in 2025. Ammonia satisfies 8% of global shipping fuel demand under the Net Zero Emissions by 2050 scenario, while hydrogen meets 2%. Finally, after many years of being disregarded owing to technological hurdles, enthusiasm for hydrogen for aircraft uses has reawakened. Airbus took the first important move in this direction in 2020, announcing an ambitious plan to create unique hydrogen aircraft concepts with a range of up to 200 passengers and a range of 3 700 kilometers, to commercialize a hydrogen aircraft by 2035. Furthermore, Boeing has collaborated with Australia's Commonwealth Scientific and Industrial Research Organisation to release a hydrogen roadmap for the aviation sector, which examines hydrogen's potential in aircraft and airport applications (International Energy Agency, 2021).

Smaller businesses like ZeroAvia and Universal Hydrogen are also developing hydrogen aircraft for short-haul flights. While direct hydrogen usage in commercial aviation is not likely to be economically feasible until the mid-2030s or later, hydrogen-based synthetic kerosene as a drop-in fuel for current aircraft might gain traction by 2030. In reality, in February 2021, KLM flew the first flight in the Netherlands utilizing synthetic kerosene. Synthetic kerosene satisfies more than 1.6

percent of aviation fuel consumption in 2030 under the Net Zero Emissions by 2050 scenario (International Energy Agency, 2021).

3.10 Benefits of Hydrogen Fuel Cell Vehicles

It is critical to recognize the benefits and advantages of employing Hydrogen Fuel Cell Vehicles as a viable sustainable transportation option. There are a few key aspects that distinguish Hydrogen technology and make it relevant in today's automotive industry. To properly realize the role Hydrogen vehicles may play on the road, it is essential to understand and be aware of the implications of operating HFCVs (Ajanovic and Haas, 2021). This section will go through the advantages of hydrogen fuel cell vehicles in further detail.

3.10.1 Availability of Hydrogen

Hydrogen has a lot of promise for generating heat and power in the home and for transportation. In 2013, Hyundai produced the world's first marketed fuel cell car and based on data provided by the scholars Ahmadi et al (Ahmadi et al. 2020) 225,000 houses already have fuel cells as a source of heat. Due to the scarcity of pure hydrogen on our planet, the hydrogen needed to power the fuel cells must be collected from resources in which hydrogen is a primary component. Water, fossil hydrocarbons, hydrogen sulfide, and other materials are examples of these materials. Renewable energy sources such as wind power, OTEC, and supercritical water gasification of the almond shell can provide the energy necessary to extract hydrogen from these materials. According to an IEA (International Energy Agency) assessment on the future of FCVs, the market share of FCVs is expected to reach 17 percent by 2050.

3.10.2 Driving range and Power Output

FCVs have a longer range than electric cars, making them more appealing. In comparison to traditional gasoline cars, FCVs are more fuel-efficient. They may also be scaled up to increase their power. To create the needed output, fuel cells are connected in series in a fuel cell stack. This stack can also be customized for heavy-duty use (Ahmadi et al. 2020).

3.10.3 Environmental Effects

FCEVs are substantially greener than both conventional (ICE) and hybrid electric vehicles (HEV) when it comes to measuring environmental effects. Diesel and gasoline cars will be prohibited from the roads in the United Kingdom by 2040, while Europe intends to decrease 80% Greenhouse gas emissions by 2050. Fuel cell electric vehicles (FCEVs) run on hydrogen. Hydrogen may be obtained in a variety of ways through natural processes (Tanç et al. 2019).

The investigation done by the scholars Colella et al (Colella, Jacobson, and Golden, 2005) yielded three significant findings. First, for a range of reasonable HFCV efficiencies and hydrogen production methods, replacing the existing fossil fuel on-road vehicle fleet (FFOV) with a hydrogen fuel cell vehicle fleet would lead to a significant reduction in air pollutant emissions, even when compared to a switch to hybrid-electric gasoline vehicles, because combustion products are eliminated at the internal combustion engine (Colella, Jacobson and Golden, 2005). Most kinds of pollutants related to air pollution, such as nitrogen oxides (NOx), volatile organic compounds (VOCs), particulate matter (PM2.5 and PM2.5–10), ammonia, and carbon monoxide, will decrease in the net amount in all HFCV scenarios (Colella, Jacobson and Golden, 2005). With a fossil fuel like natural gas, as well as a renewable source like wind, similar reductions in air pollutant emissions were obtained. Second, replacing FFOV with hybrid electric vehicles or HFCV with fuel produced from natural gas, wind, or coal would cut greenhouse gas and particle emissions by approximately 6%, 14%, 23%, and 1%, respectively. Because of the electric power needed for hydrogen compression, considering reliance on conventional power plants for electricity in the hydrogen supply chain, this HFCV fleet would create some more Carbon footprints at the power plants compared to the FFV. However, the HFCV fleet would emit less Carbon dioxide across the full supply chain, covering vehicle operation. Lastly, even if HFCVs are powered by a fossil fuel like natural gas, no carbon is sequestered, and 1% of the methane in the feedstock gas is released into the atmosphere, this scene still results in a significant 14 percent reduction in Carbon dioxide equivalent GHG emissions and reduced air pollution compared to the 1999 FFOV fleet. This result is due to the lower carbon content of natural gas per unit of fuel energy compared to petroleum fuel; a high energy conversion efficiency in transforming natural gas to hydrogen via steam reforming reactions; the increased efficiency of electric drive trains compared to mechanical drive trains and the higher performance and reduced emission characteristics of fuel cells compared to IC Engines (Colella, Jacobson and Golden, 2005).

3.11 Challenges Hydrogen

In recent years, research has backed up the claim that only a small number of extremely wealthy people may be regarded as an initial market for fuel cell automobiles (Forthoffer and Frenette, 2009). These people will be motivated by a desire for cutting-edge technology as well as environmental concerns. To make an FCV appealing to the general public, all concerns influencing commercial feasibility must be addressed (Ahmadi et al., 2020). Hydrogen has a lot of beneficial qualities and a lot of promise to help with the energy transition and emissions reduction, particularly in the transportation sector. However, certain significant obstacles must be conquered before the advantages of hydrogen and FCV can also be realized (Ajanovic and Haas, 2021).

3.11.1 Extraction of Hydrogen

Despite being the most common element in the universe, hydrogen is rarely seen alone in nature. Hydrogen is mostly generated nowadays by reforming natural gas. If the reformation is done in a central plant, pollutants can be collected in this way. Other alternatives, such as direct solar hydrogen from landfill methane and hydrogen produced by microorganisms, are constantly being investigated. If electrolysis is utilized to create hydrogen, an expansion in power output may be required to meet the hydrogen demand, but this rise may be minor. Nuclear, wind, solar, hydroelectric, and geothermal power are all environmentally friendly ways to create electricity. The majority of hydrogen will be created from natural gas at the outset of the hydrogen economy, but society will gradually migrate to more optimal sources of energy, such as wind and solar, as time goes on (Manoharan et al., 2019).

Shin, Hwang, and Choi (Shin, Hwang, and Choi 2019) elaborate on this point, suggesting that depending on the hydrogen generation processes, HFCVs can also generate GHG emissions. In contrast to electric vehicles, however, the hydrogen needed in Korea may be obtained from petrochemical waste. In other words, Korea has a significant chemical engineering industry, which provides it with a plentiful supply of hydrogen produced as a by-product of chemical processing. However, even if supply is plenty in the short term, it may not be sufficient in the long run. As a result, the environmental effect of HFCVs should be recalculated based on realistic situations (Shin, Hwang, and Choi, 2019).

Although HFCVs emit no pollutants when driving, the manufacturing of H2 is not pollution-free. H2 must be created from molecules that contain it through certain procedures to serve as an energy carrier. Currently, fossil fuels provide about 99 percent of global H2. Only a small percentage of hydrogen is created by the water electrolysis process (Wang et al., 2020).

3.11.2 Cost

A great roadblock to commercialization is cost, as fuel cells are still prohibitively costly. Many parts used in fuel cells must be custom-made, and as a result, they can be rather costly. However, as technical processes improve and components are mass-produced, their costs will fall (Manoharan et al.,2019). This viewpoint is supported by Ahmadi et al (Ahmadi et al. 2020), who state in their study that the two primary issues of a fuel cell are durability and manufacturing cost.

One of the primary impediments to wider adoption and quicker penetration of FCVs is cost. FCV and hydrogen mobility is currently highly costly and not competitive with conventional automobiles or other options such as rechargeable electric cars. The most significant factor in the deployment of FCVs is to lower investment costs. Various FCV versions are already commercially available (e.g. Toyota Mirai, Honda Clarity, Hyundai Tucson, etc.) FCVs are equivalent to traditional fossil-fuelled cars in terms of driving range, which ranges between 400 and 550 kilometers per tank, and refueling time, which is 3-5 minutes (Ajanovic and Haas, 2021).

3.11.3 High Voltage Degradation

Although fuel cell vehicles have a great potential for energy conversion efficiency, they may experience significant voltage degradation rates, reducing their lifespan durability. As a result, operating expenses grow, and it is no longer competitive with traditional gasoline cars. Degradation occurs when there are a lot of stops and starts, which puts a lot of strain on the fuel cells (Ahmadi et al., 2020). As a result of the voltage dips, the stack's performance and efficiency deteriorate (Ahmadi et al., 2020).

3.11.4 Infrastructure

FCEVs have several drawbacks, including a restricted range, a lack of hydrogen fueling stations, storage and safety issues, high pricing, and even less recognition and appeal. The lack of a standard network for fuel-cell cars is one of the most significant roadblocks, as is the greater expense of both gas and liquid hydrogen. The careful maintenance of hazards such as overheating and overfilling in the Hydrogen Refueling Systems to be developed is one of the causes of such expenses. Automobile firms like Toyota, Mercedes-Benz, Honda, General Motors, Hyundai, and Nissan are trying to grow and commercialize FCEV. The most serious issues, however, are the lack of widespread infrastructure (Tanç et al., 2019).

A station's hydrogen can be delivered at pressures of up to 875 bar (Schwoon, 2007). There are presently no traceable capabilities in laboratories for certifying flow meters used in hydrogen refueling stations at 700 bar NWP using hydrogen under identical pressure and temperature conditions. Aside from the technological difficulties, working with such a high pressure of hydrogen is extremely hazardous, and most laboratories would not be prepared to manage it from a health and safety standpoint. There are currently just a few options for calibrating flow meters that work at high hydrogen pressures (Schwoon, 2007).

Hydrogen has several drawbacks, including a lower energy density than liquid hydrocarbon fuels (but greater than modern batteries), comparatively expensive transportation, storage, and dispensing costs in compressed or liquefied form, and a lack of widespread infrastructure. Hydrogen also suffers the standard problems that new technologies face: a lack of scale economies, a lack of vehicle diversity, public misconceptions and lack of understanding, risk aversion, and the need to build a suitable institutional framework.

The requirement to build an adequate and cost-effective refueling infrastructure for hydrogen is proving to be a significantly more difficult obstacle to overcome than it is for electricity or sustainable liquid fuels. The availability of a refueling infrastructure is crucial to the value of a hydrogen car to a potential customer. Refueling infrastructure, on the other hand, is not commercially feasible without enough hydrogen cars and their need for hydrogen. As the majority of the benefits of hydrogen vehicles flow to society as a whole in the form of cleaner air and climate change mitigation rather than to individual vehicle owners, public policy assistance is required to overcome the automotive infrastructure challenge. Furthermore, achieving the full environmental advantages of hydrogen-powered mobility necessitates assuring that hydrogen is generated from non-polluting, near-zero-carbon energy sources, at least on a significant scale in the long run (Greene, Ogden, and Lin, 2020).

3.11.5 Issue of Platinum

Fuel cell technology is used in hydrogen cars, and in the case of PEMFCs (Proton Exchange Membrane Fuel Cells), a specific quantity of platinum is required to catalyze the reaction at the electrodes. Platinum is a scarce and valuable mineral, and it is vitally important since no other material can currently perform the same function in fuel cells. Platinum is already widely utilized in jewelry, the steel industry, and the automobile sector for the manufacture of catalytic converters (up to 100 t/year of the 200 t/year available on the market for the latter). Between now and 2050, a large growth of the market for platinum for catalytic converters is projected due to the growth in individual mobility in rising nations (Reverdiau et al., 2021).

3.12 Life Cycle Assessment

Fuel cell vehicles, like other zero-emission options, have significant acceptance challenges. The infrastructure for hydrogen fueling is limited, the cost of manufacturing and distributing hydrogen fuel to service stations is presently expensive at low volumes, and creating hydrogen from fossil fuels is still significantly cheaper than producing hydrogen from renewable energy. As a result, an expanded strategy to develop and strengthen the infrastructure for hydrogen cars is one of the most significant steps in the integration of HFCVs into the automotive industry. This portion of the research paper will look at the numerous procedures that are necessary for optimal infrastructure as well as the scope of development.

3.12.1 H2 production technologies

Hydrogen is a secondary power source that may be generated from any primary energy source, including fossil, nuclear, and renewable energy sources. It can address some of the most pressing energy and environmental issues as an emission-free energy transporter (Ajanovic and Haas, 2021). It may be made with a variety of energy sources and manufacturing techniques. These various manufacturing systems, on the other hand, are at various degrees of development. Currently, the most extensively utilized technique of hydrogen generation is steam reforming of natural gas.

This method produces around 71 percent of hydrogen (Ajanovic and Haas, 2021). However, for every kilogram of hydrogen generated, around 10 kilograms of CO2 are created. Hydrogen manufacturing from renewable energy sources is of particular relevance for the future. Electrolysis is the only established technique that can produce hydrogen from renewable energy sources. This technique accounts for just 0.1 percent of global hydrogen generation. Furthermore, the majority of the power utilized in this operation now comes from non-renewable sources. This procedure necessitates the use of both power and water. Water is required for every kilogram of hydrogen, which might be a problem in water-stressed places. The comparatively low production costs of natural gas are a primary factor for its present widespread use in hydrogen generation (Ajanovic and Haas, 2021).

First, there are two major cost drivers at the manufacturing stage, particularly for hydrogen generated by electrolysis: one is the high capital cost of production equipment such as electrolyzers, and the other is the cost of energy, particularly electricity. When comparing the cost of electrolysis utilizing renewable energy to grid power, the expense of electrolysis using renewable energy is significantly higher. Distributed hydrogen production has a greater cost of production than centralized large-scale production, which benefits from huge economies of scale (Li and Taghizadeh-Hesary, 2022).

Hydrogen may be made from a variety of traditional and renewable sources (He et al., 2021). Natural gas (NG) to hydrogen (H2) through steam methane reforming (SMR) is the most cost-effective and widely utilized technology, accounting for around 76 percent of worldwide hydrogen supply. Coal gasification is the second most frequent technique and is also economically viable (He et al., 2021). GHG emissions as well as other environmental effects, on the other hand, are a key problem for these fossil-fueled methods. To solve this problem, carbon capture and storage (CCS) solutions are being developed. Thermochemical (e.g., pyrolysis, gasification) and biological pathways are the two basic types of biomass-to-H2 processes (e.g., bio photolysis and fermentation). Gasification using water-gas shift is a proven process that may be used to convert biomass to hydrogen (He et al., 2021). Water electrolysis is commercially available, although it is energy-intensive and has traditionally only been used on a small scale. Hydrogen may also be manufactured using electricity supplied from renewable energy sources like wind and solar power, rather than grid electricity (He et al., 2021).

The Toyota Mirai is a successful hydrogen fuel cell car that employs a proton exchange membrane fuel cell (PEMFC) stack, a high-pressure hydrogen tank, a nickel-metal hybrid battery, and an electric motor (Deviatkin et al., 2016). At a much higher gasoline price, the hydrogen infrastructure, which includes hydrogen manufacturing processes and liquefaction, transportation, and fueling stations, might emerge (Deviatkin et al., 2016).

3.12.2 Hydrogen storage system

A hydrogen storage tank, pressure sensor, electromagnetic valve, temperature sensor, hydrogen supply pipeline, hydrogen supply electromagnetic valve, hydrogen pipeline pressure sensor, hydrogen pipeline, pressure relief valve, and hydrogen filling switch make up FCV's hydrogen storage system. The hydrogen system is shown in this way. The hydrogen pipeline consists primarily of a hydrogen filling port, a unilateral valve, a pressure sensor, a filter, a relief valve, pressure relief devices (PRD) vents at the tank end and mouth, a pressure relief valve, an electromagnetic valve, a flexible tube, a tank, and other components. The hydrogen filling port is primarily connected to the hydrogen filling nozzle, and care must be taken to avoid leaking at the connection between the hydrogen filling nozzle and the vehicle's hydrogen filling port. The unilateral valve is a device that prevents gas from flowing in the opposite direction. The pressure sensor will sense the pressure of hydrogen that has been provided. The filter primarily filters out certain particles while also providing high-quality hydrogen for the fuel cell. When filling hydrogen to the maximum pressure limit, the PRD is mostly employed to discharge the hydrogen (Zhang et al., 2022).

3.12.3 H2 delivery pathways

Hydrogen must be stored and distributed to refueling stations if it is generated in a big centralized facility. The cost of delivering hydrogen is determined by the volume of hydrogen provided, the distance traveled, the type of storage (compressed gas or cryogenic liquid), and the manner of distribution (Greene, Ogden, and Lin, 2020). Hydrogen, like natural gas, may be transported via a gas pipeline. In the United States, about 1600 km of industrial hydrogen pipelines exist today, largely supplying refineries and big chemical customers. However, huge energy flow rates and geographically concentrated needs, such as a pipeline feeding a major refinery or a fully developed hydrogen energy market in a large metropolis, make hydrogen pipeline supply economically viable. Pipelines are now too expensive since hydrogen demand for fuel cell cars is tiny and geographically distributed. Hydrogen is transported by truck or manufactured "onsite" at the refueling station from natural gas or electricity for these purposes. Compressing hydrogen is more energy-efficient and cost-effective than liquefying it, although liquid hydrogen has a far higher energy density. As a result, compressed gas is chosen for short-distance truck delivery of tiny amounts of hydrogen, whereas liquid hydrogen is transported in larger volumes over longer distances by truck (Greene, Ogden, and Lin, 2020).

The H2 distribution path begins at the HFCEV's onboard storage tank and finishes at the production facility gate. Compression, storage, precooling, and dispensing at a refueling station are all part of the delivery pathway, as is liquefaction or compression at a distribution facility, transportation, and distribution. H2 is generated at low pressure (20 bar) via SMR and electrolysis processes, and it can be compressed before being transported via pipes from the production facility to the distribution terminal. However, the demand for H2 in initial HFCEV deployment markets may not warrant the construction of a specialized H2 pipeline network. H2 is compressed or liquefied at the distribution terminal before being loaded into pressurized gaseous tube-trailers or cryogenic-liquid tanks for transit to refueling stations. Pathway for gaseous delivery H2 can be compressed to a pressure of between 200 and 500 bar and placed onto gaseous tube-trailers for transport and distribution to filling stations. The payload of a tube trailer is determined by the tube volume, quantity of tubes, and loading force, and is restricted by the 80,000-pound gross vehicle weight limit set by the US Department of Transportation (36,287 kg). Tube-trailers are currently equipped to transport 300 to 1100 kg of compacted gaseous hydrogen (G.H2), which may be discharged or switched with an "empty" tube trailer at the demand location. At a refueling station, a tube trailer delivers H2 to a gaseous compressor, which compresses it to 1000 bar before storing it in a high-pressure buffer storage solution for dispensing into vehicle tanks. The dispenser uses a refrigeration mechanism to manage the flow of H2 from the high-pressure reserve storage into the vehicle tank, preventing the HFCEV tank from overheating (Liu et al., 2020).

3.12.4 Liquid delivery pathway

Liquid nitrogen is commonly used to precool H2 from ambient temperature to 80 K, then a sequence of compression and expansion procedures to achieve 20 K, the temperature required for H2 liquefaction. The liquid hydrogen is then distributed onto cryogenic-liquid tankers for transportation to refueling stations, after being placed into massive cryogenic storage tanks at a neighboring distribution terminal. A liquid tanker transports around 4 metric tons of L.H2 to one or more refueling stations, where it will be unloaded into cryogenic tanks. The cryogenic tank at a refueling station holds H2 at a pressure of 2-8 bar and feeds it to a high-pressure pump, which raises the pressure to above 700 bar, warms the pressured H2 to 40 C through a heat exchanger (known as a vaporizer), and discharges it into the vehicle tank sources (Liu et al., 2020). Alternatively, at 350 pressure and 230 C, the cryo-pump may be utilized to directly pump cryogenic H2 into a cryo-compressed vehicle tank . The demonstration phase of cryo-compressed dispensing is underway. It promises to boost the inbuilt storage energy density of HFCEVs, extending their driving range. Because of its larger payload, liquid hydrogen distribution in tube-trailers is often more cost-effective than compressed hydrogen delivery in tube-trailers, particularly over long distances (4 vs. 1 metric ton). However, depending on the H2 supply pressure and the efficiency of the expansion and contraction operations during liquefaction, the H2 liquefaction process takes between 11 and 15 kWh per kilogram of H2. As a result, it's critical that the electricity needed for liquefaction be inexpensive and comes from low- or zero-carbon sources (Liu et al., 2020).

3.12.5 Hydrogen refueling station

Hydrogen refueling stations (HRSs), like gas filling stations, are fuel supply infrastructure that is specifically intended to replenish hydrogen into hydrogen FCVs. They are both a crucial cornerstone for facilitating the development and operations of FCVs and a bottleneck in their broad implementation. HRS development and deployment are necessary for the commercialization of hydrogen technologies in the automobile sector to reach a breakthrough. There are two varieties of HRSs now available, depending on the location of hydrogen generation: HRSs with external hydrogen supply and HRSs with on-site hydrogen production.

The hydrogen compressor, hydrogen storage tank, dispenser, control system, safety monitoring system/device, and other components of HRS with external hydrogen supply are mainly: hydrogen compressor, hydrogen storage tank, dispenser, control system, safety monitoring system/device, and so on. The HRS with internal hydrogen generation adds a sub-system of producing hydrogen to the HRS using an external hydrogen supply. The HRS footprint may be divided into four areas based on functionality: gas unloading, compression, hydrogen storage, and filling. The most prevalent hydrogen storage methods are high-pressure gaseous storage, liquid hydrogen storage, and filling in metal hydride. The major hydrogen storage option utilized in HRSs and FCVs is high-pressure hydrogen storage.

The difference in pressure between the storage and the vehicle-mounted hydrogen tank allows for hydrogen filling at the HRS. As a result, if the vehicle-mounted hydrogen storage tank's standard is 35 MPa, a pressure of roughly 40–45 MPa must be filled. When filling hydrogen tanks, high-pressure hydrogen should be kept separately in two to three vehicle-mounted hydrogen storage tanks. It automatically shifts to filling the next high-pressure hydrogen storage tank once the pressure of the vehicular hydrogen storage tank and the filling mechanism is balanced. Currently, vehicle-mounted hydrogen storage solutions with pressures of 35 MPa and 70 MPa are routinely employed in FCVs.

The 35 MPa vehicular hydrogen storage tank is inferior to the 70 MPa in terms of decreasing power consumption and boosting utilization rate, but it cannot satisfy the criteria for long-distance and high-load drive cycles. The 70 MPa hydrogen storage system, on the other hand, will quadruple the energy consumption losses of HRSs while raising the cost of equipment and materials for the hydrogen tank. As a result, they are only economically viable for passenger vehicles.

Liquid hydrogen storage, as well as hybrid cryogenic high-pressure hydrogen storage, are the development directions for foreign commercial vehicles, while hybrid cryogenic high-pressure hydrogen storage is the development path for passenger automobiles. Mechanical and non-mechanical hydrogen compressors are the two types of compressors usually employed in HRSs. Because of its capacity to entirely separate from hydraulic fluid and lubricant existing inside the compressor design, diaphragm compressors are employed.

A hydrogen filling machine, hose, gas taking priority control device, user display panel, flow metering, hydrogen filling nozzle, pull-off valve, throttle protection, pipeline, valve, pipe fittings, enclosure, control system, pressure sensor, temperature sensor, filter, safety system, and so on are the main components of HRS' hydrogen filling system. In general, there are two types of hydrogen filling dispensers: 35 MPa and 70 MPa, which are designed to satisfy the needs of different cars (Zhang et al., 2022).

3.13 Safety and general hazards

Fuel tanks that store hydrogen, fueling receptacles that allow hydrogen to be filled, fuel supply lines that supply hydrogen, fuel cell stacks that transform hydrogen to electricity, electric motors that push the vehicle, and battery packs that store electricity are all common features of hydrogen fuel cell vehicles. Although the system structure of various automakers' cars may change, the system components and risks are all the same. In general, there are two types of dangers associated with hydrogen fuel cell cars. One has to do with electrical systems, while the other has to do with hydrogen systems. The high voltage components of electrical systems, such as the battery, the electric motor, and the high voltage cables, pose a risk. For starters, an electric shock to a human might result in significant harm. The malfunctioning high voltage batteries or wires may charge the neighboring components electrically in the case of a car collision. People who come into touch with those electrically charged parts will be shocked. The high-voltage battery, on the other hand, might cause a fire. Due to the prevalent cause failure of thermal runaway situations, electric car fires caused by batteries are not uncommon. Additionally, the battery fire poses a substantial hazard to the onboard hydrogen system, and electric sparks from damaged high voltage components significantly enhance the risk of igniting in the event of hydrogen escapes. Hydrogen discharges are the source of hazards in hydrogen systems. Continuous releases of hydrogen, such as a hydrogen leak, or sudden releases, such as a catastrophic explosion of a hydrogen tank, are both possible. The dangers they pose might be physiological, physical, or chemical. Large emission of hydrogen might cause breathing problems or possibly asphyxiation owing to a lack of oxygen. When hydrogen from a huge stockpile leak, a health hazard might occur. However, because of the limited number of onboard hydrogen systems, it is unlikely to happen in a vehicle. In an explosion, the physical threats include blast waves and missile impacts. For example, if a hydrogen tank explodes catastrophically, the shockwave overpressures and projected pieces might inflict serious injury or death. Hydrogen flames and explosions are among the chemical dangers. People can get thermal burns from the heat and radiation produced by flames and explosions (Jack, de Souza, and Kalebaila, 2015).

3.13.1 Safety Measures

Cleaner fuels and powertrain technologies in automobiles have been hailed as a viable solution for protecting the environment by reducing petroleum use and thereby harmful exhaust emissions. Although hydrogen may be stored in gaseous, liquid, or solid form, compressed gas storage at high pressure (35 or 70 MPa) is the most efficient mode of transportation because of its technological simplicity, promising dependability, increased energy efficiency, and availability (Foorginezhad et al., 2021). Despite their benefits, hydrogen fuel cell electric cars have a number of drawbacks, including limited range, storage and safety concerns, high cost, and low popularity. Refueling with high-pressure hydrogen, on the other hand, frequently causes an immediate boost in storage cylinder inner temperature, lowering the state of charge (SOC), vessel wall damage, and safety concerns. Furthermore, because hydrogen is an odorless and colorless gas, it is critical to develop sensors capable of detecting leakage. Furthermore, it has not been regarded as a popular fuel due to its flammability and poor ignition energy. However, it is widely employed in hydrogen fuel cell automobiles all over the world. Fuel cells are also criticized for having poor gravimetric and volumetric densities of hydrogen fuel. In terms of using hydrogen as a fuel in automobiles, safety concerns should be closely monitored to assess and mitigate any risks. Because a fuel cell system has a distinct energy source and converter, it is somewhat complicated; thus, assessing safety and reliability problems is critical for portable applications (Foorginezhad et al., 2021).

3.13.2 Safety in usage

In general, hydrogen is a non-explosive and non-reactive gas, hence a reactant is always necessary. Because hydrogen is 14 times lighter than air, it is buoyant and safer than other fuels in an open environment, dispersing quickly in a ventilated space and releasing less energy during the explosion (Foorginezhad et al., 2021). Hydrogen would instantly scatter in an open space to below its flammability limit due to its buoyancy, and a hydrogen explosion emits less energy in a given volume than other fuels like gasoline and natural gas (Foorginezhad et al., 2021).

Furthermore, hydrogen interacts strongly with a variety of surfaces, has a high solubility, and diffuses freely through practically all materials at room temperature. Hydrogen may permeate as a molecule in non-metals, causing irreversible damage to elastomers during supersaturation. Furthermore, hydrogen detaches on metal surfaces before diffusing as a single atom into the metal. Hydrogen exposure would impair numerous features of materials used to manage and distribute gaseous hydrogen as a fuel. In addition, hydrogen escapes quicker than other gases and, in some cases, might detonate if mixed with air. As a result, precautions must be taken to prevent hydrogen from escaping (Foorginezhad et al., 2021).

3.13.3 Flammability

In comparison to certain other chemical or physiological features, hydrogen's flammability is regarded as the most dangerous. The energy carrier property of hydrogen is often linked to its flammability, and it has been demonstrated that a mixture of combustible gases and air will burst in adequate quantities and energy to initiate a reaction. It can also be shown that a weak spark will ignite any gas/air mixture, making it easy to start a fire. Because hydrogen has a far wider flammability range than other fuels, it ignites much more easily and transitions to explosion much more quickly. Meanwhile, because hydrogen is more flammable than diesel, gasoline, or methane, lean-burn combustion methods may be used with hydrogen as a fuel. The most major disadvantage of hydrogen utilization, according to experts, is its low initial energy as well as its broad flammability range, which allows hydrogen mixtures to ignite prematurely. As a result, caution must be exercised while using hydrogen in a fuel cell since hydrogen ignites with an unseen flame (Foorginezhad et al., 2021).

3.13.4 Leakage due to small molecules

Because hydrogen is the tiniest and lightest atom, it may easily leak from sealing areas such as valves and flanges. As a result, while using hydrogen in fuel cells, safety considerations must be considered. Hydrogen molecules can penetrate materials that are impervious to other gases or dissolve on the surface due to their tiny size. The diffusion of atomic hydrogen into a material weakens its mechanical integrity, resulting in internal blisters that promote fracture propagation. Low viscosity and tiny molecules also demand a gasoline tank gasket. Most materials are substantially weakened by hydrogen thanks to its distinctive nature (high pressures and tiny molecules). Entrapped methane bubbles formed by the hydrogen and carbon interaction induce fissures, fractures, or blisters in carbonaceous metals owing to gas pressure in internal gaps, a phenomenon known as 'hydrogen embrittlement.' Chromium-rich steels, chromium-molybdenum alloys, and composites reinforced polymers are now shown to be resistant to hydrogen embrittlement (Foorginezhad et al., 2021).

3.13.5 Safety in refueling

One of the most difficult aspects of deploying fuel-cell cars on a broad scale is ensuring that they can be refueled safely and quickly. The storage tank fails due to a spike in gas temperature caused by high-pressure refueling. Apart from that, as the temperature rises, the density of hydrogen decreases, resulting in a drop in eventual mass delivery and a reduction in driving range, whereas chilling the gas before injection might be a potential approach to meeting safety criteria. As a result, the highest temperature of the wall within the hydrogen tank and the fueling pressure has been set at 358 K and 125 percent of the determined pressure, respectively, by GTR-HFCV, SAE-J2579, and ISO-15869. Furthermore, it has been found that the cylinder's starting pressure has a substantial impact on temperature. Higher pressures hold more hydrogen in a tank, while a smaller ratio between final and beginning pressures reduces temperature rise during refueling. Increased filling rate, on the other side, leads to a rise in ultimate temperature. A temperature rise is caused by three primary thermodynamic phenomena: heat generation from the kinetic energy of fast-flowing hydrogen transformed into internal energy gas, hydrogen expansion through a throttling valve (Joule-Thomson effect), and hydrogen compression in the tank during filling. Overall, increasing the temperature lowers the vessel's state of charge (SOC), posing a safety risk. As a result, quick charging should be properly examined to decrease associated hazards. Multi-stage filling with pre-cooling has lately been used to reduce the temperature rise in this way. In terms of cylinder dimensions, it is shown that a big length/diameter causes local temperature increase. When the ambient temperature is taken into account, it may be deduced that high temperatures result in less heat emission (Foorginezhad et al., 2021). When the temperature of the starting gas and the wall rises, the maximum temperature exceeds the safety limitations. Fueling characteristics such as beginning gas temperature and pressure, ambient temperature, filling rate, and vessel diameter should all be closely monitored to assure safety (Foorginezhad et al., 2021).

3.14 Summary

Only a small amount of hydrogen is utilized in the transportation sector due to the shortage of fuel-cell automobiles on the road today. Hydrogen combined with a fuel cell is being used in development programs and niche markets for trucks, buses, trains, forklifts, and mining vehicles. Like other technologies, the initial research and implementation phases of fuel cell technology are heavily reliant on government restrictions and incentives. It can be observed that the largest level of implementation in the transportation industry is in passenger light-duty cars, while light commercial vehicles remain unaffected. China is a leader in the integration of buses and trucks, whereas Korea, the United States, and Japan are leaders in the integration of FCEV passenger light-duty cars into their transportation sectors (International Energy Agency, 2021). By the end of June 2021, the International Energy Agency (IEA) reported that there were more than 40 000 FCEVs on the road throughout the world. The creation of supporting infrastructure should accompany the deployment of fuel cell cars. Japan remained in the first spot with almost 140 refueling stations, followed by Germany (90) and China (85). Alstom has been a trailblazer in Europe's rail business, having completed a successful 18-month trial of two trains in Germany in 2020, which was followed by tests in the Netherlands, Austria, and Italy. Hydrogen trams, line-haul locomotives, switching locomotives, and passenger trains are all at various stages of development. The International Marine Organization is attempting to decarbonize maritime fuels, with hydrogen and ammonia expected to play a larger role in the future. Hydrogen fuel cells have been demonstrated on a variety of coastal and short-distance vessels since the early 2000s, although none are now economically feasible. Hydrogen-based fuels, particularly ammonia, are also attracting the attention of large oceangoing vessels (International Energy Agency, 2021). Hydrogen technology is distinguished by a few important features that make it relevant in today's automobile sector. These benefits include the widespread availability of hydrogen, a longer driving range, and higher power output, as well as significant environmental benefits (Ajanovic and Haas, 2021). However, there are still several obstacles to overcome, like the extraction of hydrogen, its high cost, high voltage deterioration, insufficient infrastructure, and the shortage of platinum, which is required for fuel cell manufacture (Ahmadi et al., 2020). As a result, for hydrogen to become a viable choice, infrastructure upgrades and safety measures must be implemented to make its production and use efficient and practicable.

4 Qualitative Research

4.1 Scope of the Study

An empirical study is essential to quantify information that a study wants to evaluate and to give a factual basis to the literature presented. The purpose of this empirical part of the Research Paper is to identify and analyze the perception of the general public towards the introduction of Hydrogen vehicles as an environment-friendly alternative to existing models in the market. This will help to broaden the scope of the study and put more emphasis on a more practical and realistic view of the current scenario in the public eye. The empirical section is carried out in a form of qualitative research, in particular, a survey regarding the topic on hand. The design of the survey has been structured similarly to previously conducted research in the field. Summarizing the results of the survey contributes to forming a deeper understanding and a better assessment of the awareness and accessibility of Hydrogen- fueled vehicles in the current market.

4.2 Objective of the Study

The objective of the survey is to determine how the alternative of Hydrogen fuel in vehicles is perceived by ordinary citizens. Another objective is also to interest the respondents in the potential of Hydrogen energy as a potential wider-accessible alternative for the vehicle market. The qualitative analysis will support the literature discussed in the paper and will grant the observations mentioned in the other parts of the paper additional validity.

4.3 Research Methodology

The design of the survey was built on principles that have been taken into account in previously done research. A questionnaire was conducted in the form of an internet survey from the time frame of November 2021 to January 2022. It was an online survey and was only filled out voluntarily by the participants. The survey was made widely available through social media and extensive sharing by friends and family.

Different statistical approaches are utilized to more fully assess the data from various angles during the analysis process and enhance the comprehension of the results, which is aimed at improving accuracy and scientific conclusions drawn from the results.

4.4 Limitations

The empirical results reported herein should be considered in light of some limitations. The questionnaire's design was influenced by past research and might be prone to personal bias. The results of the survey were presented in terms of people's social attitudes. It is also possible that significant steps concerning hydrogen energy were overlooked. It should be noted, however, that this questionnaire was designed for ordinary individuals with no professional understanding of the research matter and varying levels of education.

As a result, the language and substance of the survey were tailored to the responders. It should be noted that the survey given in the research was technical and involved hydrogen energy, which is still relatively unknown and unpopular. Furthermore, the sample size was relatively small compared to other professional surveys, which was most likely owing to the nature of the subject. This in turn meant that only a limited number of people were willing to participate in the study.

The research was done from a societal rather than a technical standpoint. The focus of the study was on the respondents' opinions, behaviors, and attitudes, as well as the engineering solutions that professionals in the hydrogen energy business have yet to address. The survey was sent through various social media sites and the authors' closest professional connections. This might have influenced the respondents' structure and, as a result, their responses. It might also have influenced the respondents' age and preferences. The study focused on responders from only a few nations, which might also have had an impact on the results. Future research, according to the authors, should include responses from a varied demographic group.

4.5 The Structure of the Survey

The body of the survey consisted firstly of a general section that comprised of a collection of demographic data of the respondent such as Nationality, Age, Gender, Professional Status, Education, and Residence. The next section of the survey then consisted of three parts, which were 1) Environmental Protection 2) Hydrogen energy and 3) Use of hydrogen fuel. These were then again divided into three parts that contained 5 statements. The respondents were then asked to indicate their level of agreement with the given statement. The statements were rated on a five-point Likert scale, with 1 indicating full disagreement and 5 indicating perfect agreement. The assertions were crafted to show flaws in society's motive to create hydrogen energy, therefore pinpointing the most difficult obstacles to overcome.

Qu 1. Environmental Protection

A. I feel responsible for protecting the environment.

B. My actions have an impact on the environment.

C. People should take more care of nature and take actions to prevent massive environmental damage.

D. People now have access to cutting-edge technology that benefits the environment.

E. People have access to new technologies that have a positive impact on the environment.

Qu 2. Hydrogen energy

A. Hydrogen is a clean energy source.

B. The usage of hydrogen energy does not result in the production of carbon dioxide.

C. Hydrogen has the potential to be a great source of energy.

D. People can safely use hydrogen energy.

E. The utilization of hydrogen energy has a beneficial effect on the environment.

Qu 3. Use of hydrogen fuel

A. In my nation, hydrogen-powered automobiles are available.

B. Hydrogen energy production is expensive (compared to other types of energy).

C. Hydrogen fuel station infrastructure is well-developed in my nation.

D. The usage of hydrogen fuel is risk-free.

E. I'm interested in the prospect of owning a hydrogen-fueled vehicle.

4.6 Results and Discussion

The survey sought to uncover the obstacles that must be addressed for society to embrace new energy technologies, particularly hydrogen. The filled surveys were first sorted in a process of verification for completeness. A total of 61 people responded to the poll. Due to the fact that not all the questionnaires were completed accurately in their entirety, 9 of them were dismissed. Finally, 52 questionnaires were examined further and used for the purpose of deeper analysis (Table 1).

Respondents	Quantity	Percentage
Total	61	100%
Rejected	9	15%
Selected	52	85%

Table 1: Respondents of the survey

First, the structure of the respondents' demographic data was examined (Table 2). Individual answer percentages were computed. The overall demographic data of the respondents was diversified, although several characteristics were recurring. This may be owing to the survey's uncommon topic - Hydrogen Energy. The topic might seem foreign to many people which might have led to certain participants not completing the survey. This, on the other hand, can also suggest a lower degree of awareness and understanding of the topic on hand.

Feature	Answer	Percentage
Nationality	Austrian	39.3%
	Indian	27.9%
	Czech	8.2%
	Turkish	9.8%
	German	8.2%
	Others	6.6%
Gender	Female	42.6%
	Male	57.4%
Age	up to 20	9.8%
	21-30	42.6%
	31-40	31.1%
	41-50	13.1%
	above 50	3.1%
Social/Professional status	School/ University student	31.1%
	I work	49.2%
	unemployed	11.5%
	entrepreneur	8.2%
	Pensioner	0.0%
Education	Primary Education	0.0%
	Lower secondary Education	0.0%
	Secondary Education	45.9%
	Higher Education	54.1%
Residence	village (< 5000 residents)	8.2%
	small city (5000 - 50 000 residents)	21.3%
	big city (>50 000 residents)	70.5%

Table 2: Characteristics of the respondents

While analyzing the demographic characteristics of the survey's respondents, we can make a few observations. Firstly, the distribution was balanced when comparing the gender of the respondents, with a majority of male respondents. Secondly, the majority of those who responded were from Austria and India. It can also be noted that the participants in the research ranged in age from 17 to 54 years old, with most of them being between the ages of 21 and 30. At the time of the study, most of the respondents were employed. The participants in the survey had at least completed secondary education or higher. Furthermore, the respondents were mostly from major cities with populations of over 50,000 people.

In the next step of the analysis of the results, the main part of the survey's findings was evaluated. Thus, for each statement, the individual ratings were first assessed. An examination of the association between individual assertions was then conducted using this data, taking into consideration the Scales received for each answer (Table 3).

	1.A.	1.B.	1.C.	1.D.	1.E.	2.A.	2.B.	2.C.	2.D.	2.E.	3.A.	3.B.	3.C.	3.D.	3.E.
1.A.	1.00														
1.B.	0.79	1.00													
1.C.	0.69	0.62	1.00												
1.D.	0.54	0.71	0.71	1.00											
1.E.	0.02	0.21	0.13	0.35	1.00										
2.A.	0.14	0.25	0.08	0.43	0.19	1.00									
2.B.	0.21	0.51	0.3	0.45	0.08	0.51	1.00								
2.C.	0.53	0.54	0.30	0.58	0.21	0.89	0.48	1.00							
2.D.	0.54	0.36	0.59	0.54	0.04	0.53	0.51	0.61	1.00						
2.E.	0.21	0.27	0.04	0.41	(0.02)	0.49	0.69	0.69	0.48	1.00					
3.A.	0.19	0.21	0.39	0.49	0.61	0.71	0.31	0.31	0.19	(0.09)	1.00				
3.B.	(0.05)	(0.11)	0.18	(0.18)	(0.17)	(0.06)	(0.41)	(0.41)	(0.39)	(0.34)	0.00	1.00			
3.C.	(0.08)	(0.15)	0.07	(0.16)	(0.09)	(0.16)	0.03	0.03	0.15	(0.27)	0.21	0.08	1.00		
3.D.	0.41	0.41	0.41	0.58	0.38	0.41	0.52	0.54	0.73	0.49	0.19	(0.55)	0.19	1.00	
3.E.	0.31	0.22	0.00	0.09	(0.12)	0.55	0.58	0.57	0.42	0.71	(0.36)	(0.27)	(0.29)	0.28	1.00

Table 3: Correlation matrix between individual questions

Above a correlation matrix of the various questions has been displayed. It can be concluded that there is a small positive correlation, but this value is too small to be significant. This indicates that there is just a little connection between the individual assertions on average. The highest correlation coefficient was obtained for statements “Hydrogen is a clean energy source” and “Hydrogen has the potential to be a great source of energy”. As a result of this observation, it may be claimed that connecting Hydrogen with a cleaner energy source will aid in its promotion as an alternative energy source. The most negative correlation is found for the statements “Hydrogen energy production is expensive (compared to other types of energy)” and “I'm interested in the prospect of owning a hydrogen-fueled vehicle”, which indicates that the price might influence the decision to buy a Hydrogen–fueled vehicle negatively.

The scale statistics were used for the next section of the analysis of the obtained results. The mean, variance, and standard deviation of the scale consisting of all five studied items are shown in Table 4. It should be mentioned that the adopted scale accepts values ranging from 15 (if the respondent picked the lowest possible value for all items which is 1) to 75 (if the respondent selected the highest possible value for all items which is 5). The mean of 52.4668 on this scale appears to be rather high and shows that the respondents had a favorable attitude toward environmental preservation and hydrogen energy as an alternative energy source.

Mean	Variance	Standard Deviation	No of Items
52.4668	93.36940	9.42355	5

Table 4: The Scale Statistics

Furthermore, the mean and standard deviation for the scores of individual questions and each group of questions were then determined (Table 5).

Question	Mean	Standard Deviation
1.A.	3.69	1.2
1.B.	4.12	1.18
1.C.	4.87	1.25
1.D.	4.06	1.45
1.E.	3.94	1.18
2.A.	3.97	1.21
2.B.	3.67	1.25
2.C.	4.46	1.21
2.D.	2.67	1.11
2.E.	2.98	1.14
3.A.	2.21	1.05
3.B.	3.85	1.43
3.C.	2.87	1.37
3.D.	2.94	1.15
3.E.	3.93	1.27

Table 5: Statistics of individual questions

The findings for individual statements show that the questions relating to group 1 received the greatest ratings, indicating that the respondents agreed with these claims. This is an environmental protection category, indicating that it is a pressing concern in society. This set of statements also had a considerably greater standard deviation, indicating that the assessments in this group diverged the most. For the questions pertaining to group 3, the lowest mean was found. This might imply that the respondents disagree with or are unconcerned with the comments. The utilization of hydrogen fuel as an alternative energy source is the subject of this series of questions. The lowest ratings in this category suggest that society has a limited understanding of hydrogen as an energy source and that it is difficult to access. This demonstrates that measures encouraging not just ecological but, more significantly, technological must be vigorously supported in the development and extension of hydrogen technologies. This information may be utilized to persuade the general public and enhance public perceptions of safety and accessibility.

When looking at individual questions, it's worth noting that question 1C received the highest score. This topic centered on the importance of individuals caring more about the environment and taking steps to avert major environmental devastation. Question 2C, which argues that hydrogen has the potential to be a tremendous source of energy, likewise received a good grade. This is a key signal that people believe in Hydrogen's potential as a source of energy in general, even if that potential does not yet extend to its usage in cars. The average in both situations was over 4, indicating that the respondents agreed with the claims. These are significant remarks because respondents recognize the need for environmental protection and believe in renewable energy sources. This suggests that society has, to some extent, surmounted a mental barrier concerning environmental sustainability.

The lowest mean score was given to question 3. A which was “In my nation, hydrogen-powered automobiles are available”. This is significant because it shows that many countries lack the infrastructure and accessibility required for hydrogen vehicles to become a viable part of the automotive industry. It also implies a lack of understanding about potential hydrogen-fueled automobiles on the market.

4.7 Interpretations and Findings

The primary goal of this study was to identify areas in which respondents' views regarding emerging methods for getting energy from hydrogen may be improved. The most important conclusions based on the offered study findings are that the majority of the population is prone to have some desire to participate in the preservation and protection of our environment. This suggests that there is widespread knowledge of the environment's ongoing degradation. Furthermore, the respondents are not persuaded that energy obtained from hydrogen has an appropriate degree of accessibility and safety, where safety can be defined as technical or related to availability.

Another important finding from the survey revealed that people's awareness of hydrogen as an energy source, as well as its product reliability and preservation techniques, are extremely limited. Furthermore, respondents feel that neither hydrogen technology nor hydrogen-powered automobiles are now available to them. This might be due to a lack of infrastructure and a general absence of understanding of the scope of hydrogen car development. Respondents are hesitant to consider hydrogen vehicles in their automobile selection due to a lack of understanding regarding hydrogen energy among the general public. This may be worsened by people's general apprehensions about the new and unfamiliar.

As a consequence of these findings, it is possible to conclude that countries' readiness for intense hydrogen energy development is limited. The results of the poll served to fill a research gap in public understanding and sentiment concerning the advent of hydrogen vehicles in the automotive industry. It can be a valuable technique for identifying the extent of societal obstacles associated with respondents' fear of hydrogen energy and lack of understanding about it. This limitation can be overcome by a variety of regulations and advertising that persuade people that hydrogen energy is safe and beneficial in their nation. Public awareness of this subject should be raised through various social media campaigns, TV programs, or articles in the press that show the benefits of using green energy, in particular hydrogen energy. It is impossible to convince all of society. However, convincing a proportion of society can help to overcome the barriers to implementing hydrogen energy in a given country.

4.8 Summary

An empirical investigation is required to quantify material that is being evaluated in a study and to provide a factual foundation for the literature given. The goal of this empirical section of the Research Paper is to identify and assess public perceptions of hydrogen vehicles as an environmentally friendly alternative to current models on the market. The empirical element consists of qualitative research, namely a survey on the subject at hand. The survey's goal is to find out how ordinary people think about hydrogen as a car fuel. Another goal is to pique respondents' interest in hydrogen energy as a possible vehicle alternative that is more widely available. From November 2021 to January 2022, a questionnaire in the form of an internet survey was undertaken. It was an online survey that participants only completed willingly. The survey was widely disseminated via social media and substantial sharing among friends and family members. During the analysis process, several statistical methodologies are used to analyze the data more thoroughly from multiple viewpoints and improve the interpretation of the results, to enhance accuracy and scientific conclusions generated from the results. The most important conclusions drawn from the study findings are that most people are inclined to want to contribute to the preservation and protection of our environment in some way. This indicates that the public is aware of the environment's continuing deterioration. Furthermore, the respondents are unconvinced that hydrogen-derived energy offers a sufficient level of accessibility and safety, where safety may be characterized as either technical or availability-related. The poll also found that people's understanding of hydrogen as an energy source, as well as its product dependability and preservation strategies, is quite restricted. In addition, respondents believe that neither hydrogen technology nor hydrogen-powered cars are now available to them. This might be due to a lack of infrastructure and a general lack of knowledge about the potential of hydrogen vehicles. Due to a lack of awareness of hydrogen energy among the general population, respondents are hesitant to include hydrogen vehicles in their automotive choices. People's basic apprehensions about the new and unfamiliar may exacerbate this. As a result of these facts, it is feasible to conclude that countries' readiness for rapid hydrogen energy development is constrained. The survey's findings helped to address a knowledge and sentiment gap among the public about the coming of hydrogen cars in the automobile sector. The survey's findings helped to address a knowledge and sentiment gap among the public about the coming of hydrogen cars in the automobile sector. It can be a useful tool for determining the scope of social barriers related to respondents' fear of hydrogen energy and lack of knowledge about it.

5 The Future of Hydrogen Fuel Cell Vehicles

5.1 Challenges for the Future

The present development of fuel cell cars suggests that the technology can be used in cars (Forthoffer and Frenette 2009). Hydrogen-powered fuel-cell automobiles, on the other hand, must-have designs that are functional, packaging efficient, attractive, inexpensive, dependable, and safe to gain commercial acceptance. More developments in fuel storage, fuel cell life, operating costs, and cold weather functionality will be required to build a device that meets all these criteria (Forthoffer and Frenette 2009).

5.1.1 Fuel cost and availability

"Ease of use" implies a widely accessible gasoline supply and a straightforward fueling technique. The US Department of Energy's Hydrogen Demonstration Program is working with some of the major sources of fuel to define long-term pricing goals and build a deployment plan. It's vital to assume that energy providers will construct enough hydrogen fueling stations to allow the market to plan economically. The development and implementation of a hydrogen-fueling network are challenging. The necessity to produce hydrogen with the lowest emissions of CO2 feasible is one of the most important. Hydrogen can be created using nuclear and renewable energy with low CO2 emissions, but it will be costly, restricted, and challenging to centralize. Although coal and, to a lesser degree, natural gas is plentiful and inexpensive, hydrogen production necessitates carbon capture and storage (Frenette and Forthoffer, 2009).

Other issues to consider include differing city ordinances, local production of hydrogen, delivered hydrogen, or hydrogen transmission lines, fueling hardware uniformity, working to improve stations with sufficient capacity to accommodate larger vehicle loads, and ultimately, overcoming populated region opposition to local hydrogen-fueling stations (Forthoffer and Frenette, 2009).

A potential road to hydrogen availability, according to Frenette and Forthoffer (Frenette and Forthoffer 2009), is the ‘‘lighthouse" strategy to establish fuelling capabilities on the east and west coasts of the United States. This strategy envisions a network of stations linked to a central H2 production facility, with each station assuming a sufficient vehicle load to produce positive economic returns. According to Frenette and Forthoffer (Frenette and Forthoffer 2009), at least 33% of filling stations across a wide geographic range would need to offer hydrogen before people would contemplate purchasing a hydrogen-only car.

5.1.2 Fuel quality

Fuel cells require high-quality hydrogen to minimize contamination of the fuel cell stack, as well as a reduction in performance and lifetime. In addition to access, a reliable and inexpensive method for monitoring and maintaining acceptable hydrogen purity and quality should be in place (Frenette and Forthoffer, 2009).

5.1.3 Regulations and Standards

There are several constraints to the use of hydrogen-powered vehicles that must be solved before they can be considered an acceptable alternative to conventional vehicles. Vehicle parking places, as well as the functioning of particular bridges and tunnels, parking areas, residential garages and buildings, and public ferry service, are all prohibited. Energy suppliers should be able to carry out their staging strategies swiftly and inexpensively thanks to a comprehensive and coordinated system of laws and standards developed by national, state, and local governments. These rules and requirements will have an influence on the price of FCV facilities and amenities, as well as the cost of industrial production sites (Frenette and Forthoffer, 2009).

5.1.4 Retail Dealer Investments

Retail dealers also need to invest heavily in manufacturing and assembly improvements to manage both Hydrogen in their facilities and FCV diagnostics. These investments must also provide a reasonable return to the dealers (Frenette and Forthoffer, 2009). For optimum vehicle commercialization and "no compromise" vehicle use, the ability to maintain and repair these automobiles must be available at most current service facilities (Frenette and Forthoffer, 2009). As a natural byproduct of rising quantities and retail availability, this capability will extend to some extent. However, the expense of establishing any customer service should not be overlooked (Frenette and Forthoffer, 2009).

5.1.5 Service Cost and Availability

Fuel cell automobiles, like any other vehicle, will need to be serviced and maintained on a regular basis. This assistance must be provided via a well-established and conveniently accessible service network. In addition to the hybrid-driven electrical abilities currently existent in the dealer service network, a core of skilled service engineers and technicians conversant with complicated advances in electronic controls, high-pressure hydrogen, and fuel cell technologies must be accessible. An efficient service provider of specialist hardware and software will be required to maintain vehicle downtime for repairs within commercially tolerable limits. Costs of parts and labor must also be affordable (Frenette and Forthoffer, 2009).

5.1.6 Insurance Cost

The insurance premiums for these high-tech vehicles must eventually be comparable to those for ordinary vehicles (Frenette and Forthoffer, 2009). Traffic collision insurance should be equivalent to those of regular automobiles, assuming FCV pricing are comparable to those of alternative engine technologies. To effectively compete in hazard insurance coverage for FCVs, however, insurance companies must be convinced that the technological advances do not pose an additional liability risk (Frenette and Forthoffer, 2009).

5.1.7 Competing Technologies

The majority of customers are unaware of the FCV propulsion technology, which is significantly different from automobiles powered by internal combustion engines. Even though the fuel cell stack and hydrogen storage facilities are unique and expensive, there are other aspects in an FCV that require significant cost cuts. The

FCV's systems must compete with what current carmakers and customers have come to anticipate in terms of effectiveness, cost, and lifetime. Automobile manufacturers and buyers will not invest in fuel cell technology until the systems that make up the various components of a fuel cell automobile have reached acceptable levels of cost, capacity, reliability, endurance, and safety (Frenette and Forthoffer, 2009). Battery technology, renewable energy, clean diesel, hybrid electric cars, and other technologies may suffocate the hydrogen economy's promises and restrict the economic potential of fuel cell vehicles (Frenette and Forthoffer, 2009).

5.1.8 Pricing

FCVs may someday get a premium for their zero-emissions abilities and potential to reduce dependency on fossil fuels, but the premium must be established by the market. As a result, calculating the premium is difficult and outside the scope of this thesis. Environmental and social benefits must be evaluated and accounted for in the FCV commercialization study, and they will most likely manifest themselves in damaging technological incentives, mandates, and/or taxes. The introduction of new technologies to the market may open up new pricing opportunities for FCVs. Early adopters may be willing to accept some level of premium price due to their opinions of clean-air automobiles' value (Frenette and Forthoffer, 2009).

5.1.9 Influence of Other Technologies

Other renewable technologies provide potential cost, infrastructural, and material supply concerns, which might remove or considerably delay the need for hydrogen fuel cell vehicles. Hydrogen FCVs aren't included in the well-to-wheel study, even though some of these solutions aren't true zero-emissions ideas. CO2 emissions can be created during hydrogen production, infrastructure development, and the production of materials and vehicle parts. Significant and long-term government incentives could be necessary to build a hydrogen economy (Frenette and Forthoffer, 2009).

5.2 Subsidies and Incentives

Subsidies and incentives are some of the most powerful and widely used instruments in the automobile industry for encouraging alternative energy sources. This initial surge in the technology could lead to a better collection of essential data and information for the advancement of FCV technologies, perhaps opening the way for future consumer applications (Forthoffer and Frenette, 2009). Furthermore, it appears that free-market forces alone will not be able to find a short-term remedy to the multiplicity of challenges affecting the economic viability of hydrogen-powered FCVs. To counteract traditional market dynamics, government assistance and innovative policies will be necessary. Consumer acceptability, as well as a dedication to alternative energy and a long-term financial help strategy, are all required. Furthermore, unless political instability, spiking fossil fuel costs, or worries about climate change drive demand for FCVs, the volume growth of hydrogen-fueled automobiles will likely be limited (Forthoffer and Frenette, 2009).

5.3 Recommendations

One efficient metric of carbon reduction is the use of HFCVs. The peak of the obstacle structure is designated as insufficient supporting infrastructure. From a macro viewpoint, the industry's relevant organizations and supervisory divisions should be established initially. After that, HFCV design and acceptability specifications should be examined and created. Furthermore, policy norms such as construction permission, operation oversight, and safety management should be clarified. Policy assistance for technical breakthroughs, industrialization implementation, vehicle purchasing, and building and operation should be provided at the micro-level. To assure HFCV promotion and application, policies such as favorable passage and the issuing of specific operating quotas are recommended (Wu et al., 2021).

5.3.1 Supply Chain Development

Firms essential for energy generation, distribution, and sales should build hydrogen energy infrastructure as soon as feasible. For regional hydrogen energy supply chain distribution optimization, the concept of "Moderately Advanced, Combination of Long-term and Short-term Goals, Safety and Order" is supported. The government should encourage key component manufacturers to research hydrogen technologies and to band together spontaneously to build a trustworthy and accredited component production chain that can handle technical and economic risks (Wu et al., 2021).

5.3.2 Safety supervision

It is recommended that daily emergency drill procedures and HFCV safety assurance measures be implemented. It's also important to appreciate the importance of hydrogen supply system safety management. On the agenda, it is suggested that applicable laws, supervision, and law enforcement for illegal construction and maintenance be included. Improving relevant processes and systems may also aid in the resolution of the issue (Wu et al., 2021).

5.3.3 Integrate the industrial chain

Deeper collaboration and incorporation of industrial individual components is promoted to eliminate flaws, develop and grow the industrial chain's qualities. On the one side, agglomeration advancement of hydrogen production, storage, transportation, processing, and fuel cell industry could accomplish hydrogen energy production and utilization in a closed system; on the other hand, assembled leading entities in the industrial chain could better support the HFCV industry based on the regional accessible industrial foundation and resource attributes (Wu et al., 2021).

5.3.4 Financial support

It is intended to increase the government investment fund's leadership position. To encourage and advise financial institutions to expand funding for HFCV important projects, bank-enterprise docking systems should be established. Furthermore, encouraging connected firms to be listed is a good way to relieve financial stress and increase competitiveness (Wu et al., 2021).

5.3.5 Research Advancements

In terms of technical research, the government is expected to develop innovation platforms and important laboratories. In order to develop a multi-level, varied, industry-university-research collaboration innovation system for the HFCV industry, a research collaboration between firms and research institutions should be adhered to. To enhance industrialization through scientific research, special emphasis should be directed to "bottleneck" technologies in important connections and the breakthrough of fundamental technologies (Wu et al., 2021).

The government might lead the growth of the HFCV sector by creating a vehicle promotion and application chain through demonstration scenes. Employing hydrogen fuel intercity buses, metropolitan buses, and municipal sanitary units for demonstration, using significant events as an occasion to conduct HFCV trial deployment, and using large trucks for demonstration are only a few of the recommendations. It is recommended that the potential of cross operations and long-distance passenger transportation be further developed (Wu et al., 2021).

5.3.6 Establishing a Network of Professionals

Government departments, automakers, component providers, hydrogen refueling station construction and operation units, and industry experts will form an industrial development expert committee. The committee might be able to help with the creation of useful technical requirements (Wu et al., 2021).

Emergency response, energy supply, demand management, vehicle operation monitoring, and other areas of HFCV and hydrogen energy system management all require connection methods, resulting in an internationally leading operation management chain. Supporting hydrogen energy and HFCV industry advancement-related events, seminars, and exhibits is a sensible decision. Initiatives such as hydrogen energy and fuel cell information popularization, as well as application assistance, might help to increase the social acceptability of hydrogen (Wu et al., 2021).

5.3.7 Improving the Infrastructure

Hydrogen support infrastructures include hydrogen production, transportation, refueling, required technical support, and maintenance services, among other things. They are now constructing and running in accordance with government macro-proposals rather than active corporate interests. To be more specific, by combining hydrogen production facilities with centrally controlled wind power or photovoltaic solar fields, hurdles in hydrogen production might be considerably reduced. This combination tackles renewable energy consumption difficulties by generating hydrogen energy, and it is also technically and economically practical.

There are three common transportation methods for hydrogen, including a gas trailer, gas pipeline, and liquid trailer. Liquid and pipeline transport should be recommended in the near future based on extending the existing pipeline infrastructure, increasing efficiency, and lowering prices. HRS adoption for hydrogen refueling is still in its early stages. Widespread investment in them may not lead to flawless operation, but it may lead to facility obsolescence, not to forget the initial investment's repayment. Building hydrogen refueling equipment on current gasoline filling stations is a smart solution since it ensures low deployment costs while also covering a large region (Wu et al., 2021).

5.3.8 Existing Automaker's Interest

From the standpoint of industrialization, certain manufacturers, including Toyota, Honda, and Hyundai, are investing funds and resources in hydrogen-related research, and have developed some intriguing concepts or even mass-market goods. Traditional automobile makers, on the other hand, are hesitant to accept the growing technological innovation (Wu et al., 2021). Take, for example, Volkswagen, Mercedes-Benz, and BMW. They stated that they will not devote significant resources to HFCVs, in part because they have been concentrating on EVs and favor the latter. Political initiatives alone will not be adequate to encourage their entry into the hydrogen business. Instead, it is more appealing to business interests to lead associated firms and money into the hydrogen sector and supply chain. To date, the majority of HFCV's acquisitions have been made by the government (Wu et al., 2021).

It makes sense to implement rules such as green power certificates to encourage collaboration in the development of HFCVs. Despite minor technological shortcomings, hydrogen will technically replace fossil energy as a brand-new source of energy. In particular, the public's attention to hydrogen safety issues and risks may be significantly reduced if suitable technological limits were imposed. It is recommended that more extensive national standards, guidelines, and regulatory procedures for the implementation of frontier technologies be established in order to ensure that technological advancements can help HFCV commercialization (Wu et al., 2021).

5.3.9 Societal Approval

Also, appropriate public awareness should be emphasized to convince customers that HFCVs have matured enough to surpass traditional combustive cars in major aspects, thereby dispelling their preconceived notions. Furthermore, when it comes to the challenges of low durability and short service life, mature market processes and business models can assist develop good after-sale technical services to ease the problem. Technology investment and innovation, on the other hand, are projected to fundamentally tackle the PEM durability problem (Wu et al., 2021).

Furthermore, byproduct pollution is caused by current industrial hydrogen production, which is not environmentally friendly nor clean enough, and should be banned for hydrogen production in the future, whereas water electrolysis produces no carbon emissions. Electrolysis should be encouraged as renewable energy mixes with hydrogen generation, and the by-product concern should be entirely overcome. Finally, to boost investor excitement, the government should aggressively support hydrogen-related investment across the board and invest heavily in order to accelerate long-term hydrogen development (Wu et al., 2021).

5.4 Summary

The current state of fuel cell vehicles implies that the technology can be used in vehicles. Hydrogen-powered fuel-cell vehicles, on the other hand, require practical, packaging-efficient, beautiful, affordable, dependable, and safe designs to attain commercial acceptability. To design a device that fits all of these criteria, more advancements in fuel storage, fuel cell life, operating costs, and cold weather capability will be necessary (Forthoffer and Frenette, 2009). High gasoline costs, inadequate growth, acceptable fuel quality, and government, existing automobile manufacturers, and retail dealer assistance activities must all be addressed in the future. Government aid and novel policies will be required to combat traditional market forces. Consumer acceptance is essential, as is a commitment to alternative energy and a long-term financial assistance approach. The industry's relevant organizations and supervisory divisions should be developed first, from a macro perspective. The design and acceptance standards for HFCVs should next be evaluated and produced. Norms for construction approval, operation control, and safety management should also be specified. At the micro-level, policy help for technological breakthroughs, industrialization implementation, vehicle acquisition, and construction and operation should be provided. Policies such as advantageous legislation and the issuance of particular operating quotas are advised to ensure HFCV promotion and application (Wu et al., 2021). Supply chain development, effective safety oversight, better integration of the existing industrial chain, more financial assistance, and more research into the technology are among the other recommendations for the future of HFCV deployment. It is also critical to create channels for reaching the general public, strengthen the infrastructure surrounding it, and pique manufacturers' interest in entering the hydrogen industry. Furthermore, sufficient public awareness should be stressed to persuade buyers that HFCVs have progressed to the point where they can outperform traditional combustive automobiles in significant aspects, thereby debunking their preconceived beliefs.

6 Conclusion

As government leaders, corporate leaders, academics, and technology thought leaders consider the world's climate and pollution challenges, a need for a constructive analysis in a fully integrated environment approach that recognizes mobility's energy needs as part of a larger and more exhaustive energy landscape arises. Population expansion, urbanization dynamics, improved lifestyles, and quickly expanding consumption of huge populations emerging in developing countries all lead to an increase in energy requirements that is highly geared. Existing fossil fuel usage's evident climatic effect gets increasingly severe and unpleasant.

Hydrogen is the most plentiful element in the universe, as well as the fuel for nuclear fusion, which drives our sun and sustains all life on Earth (Manoharan et al., 2019). It is also a vital component of the fossil fuels that have propelled trade, industry, and living standards forward since the beginning of the industrial revolution. Furthermore, for applications in the automotive sector, hydrogen offers important benefits over fossil fuels as an energy carrier.

The goal of this research paper is to study the best techniques for extracting the most energy to power applications in transportation focusing on hydrogen generation and use. The major objective of this thesis is to explain how hydrogen fuel cell cars might be used as an alternate driving system. Fuel cells and hydrogen have a lot of potential in the future of transportation. Countries such as the United States, China, Europe, and Japan, among others, are noticing this trend and investing their efforts on various fronts to enhance fuel cell technology, distribution network, and infrastructure. Although society is still in the early stages of awareness and deployment, hydrogen is a potentially feasible and necessary alternative energy source. Energy policymakers, energy suppliers, and technological businesses in related areas should all place a high priority on hydrogen.

The purpose of this research paper is to examine the theoretical and practical background of Hydrogen as an alternative energy source in the automobile industry. The paper's literature review focuses on a number of critical points, including the need for considerable infrastructure development and the relevance of ongoing study into the many technologies related to hydrogen as a source of energy. Despite the numerous advantages of Hydrogen as an alternative fuel source, such as its abundant supply, extended driving range, and great environmental friendliness, there are still a number of obstacles connected with Hydrogen (Ajanovic and Haas, 2021). These include infrastructural concerns as well as a high cost. Another disadvantage of hydrogen as an alternative energy source is that many people are unaware of its capabilities. The empirical section of the study paper delves more into this topic. This section attempts to track public understanding and perceptions of hydrogen as an alternative energy source in the transportation industry. The findings show that society's present awareness and knowledge of this technology are limited. This highlights the lack of promotions and policies, implying that further research and action are needed in this area.

Evolving international technologies and economic competitiveness are critical in driving the development and implementation of energy-efficient solutions. For large economies in the struggle, this progress will constitute a significant competitive advantage. It is also worth noting that hydrogen is not the only option for transitioning to sustainable energy to power global mobility. Rather, it, along with Electric Cars and other new technology, is part of the solution.

It is noted that for all of the countries that offer policy incentives for a variety of green energy options, the future transport ecosystem might be powered by a variety of technologies, depending on use cases, customer needs, and infrastructure development. However, no discussion of the battle against climate change is relevant or feasible without a thorough grasp of the possible economic incentives for governments and businesses to accept and develop new technology. Governments, manufacturers, and oil and energy firms are all working hard to advance hydrogen fuel cell vehicles, and they will certainly be on the part of the vehicles on road in the near future. If it is believed that hydrogen fuel cell vehicles have a bright future, now is the moment to demonstrate it and aim to have the necessary network and infrastructure in place.

Further research is required in areas including lowering production costs, enhancing safety and risk controls, expanding the network of refueling stations, and improving the commercialization of hydrogen. Furthermore, as hydrogen technology evolves, concerns such as the creation of fuel storage devices, enhancing cold start performance, improving cell life, and further research into alternative materials for cell membranes are some of the areas that demand greater attention.

List of References

Ahmadi, P. *et al.* (2020) "The effects of driving patterns and PEM fuel cell degradation on the lifecycle assessment of hydrogen fuel cell vehicles," *International Journal of Hydrogen Energy*, 45(5). doi:10.1016/j.ijhydene.2019.01.165.pp.3595-3608

Ajanovic, A. and Haas, R. (2021) "Prospects and impediments for hydrogen and fuel cell vehicles in the transport sector," *International Journal of Hydrogen Energy*, 46(16). doi:10.1016/j.ijhydene.2020.03.122.pp.10050-10058

Apostolou, D. and Welcher, S.N. (2021) "Prospects of the hydrogen-based mobility in the private vehicle market. A social perspective in Denmark," *International Journal of Hydrogen Energy*, 46(9). doi:10.1016/j.ijhydene.2020.11.167.pp.6885-6900

Colella, W.G., Jacobson, M.Z. and Golden, D.M. (2005) "Switching to a U.S. hydrogen fuel cell vehicle fleet: The resultant change in emissions, energy use, and greenhouse gases," *Journal of Power Sources*, 150(1–2). doi:10.1016/j.jpowsour.2005.05.092.pp.150-181

"Deloitte-Ballard white paper on fuel cells for fueling future mobility" (2020) *Fuel Cells Bulletin*, 2020(2). doi:10.1016/s1464-2859(20)30076-6.pp.1-104

Deviatkin, I. *et al.* (2016) "Comparative life cycle assessment of deinking sludge utilization alternatives," *Journal of Cleaner Production*, 112. doi:10.1016/j.jclepro.2015.10.022.pp.1-15

Foorginezhad, S. *et al.* (2021) "Sensing advancement towards safety assessment of hydrogen fuel cell vehicles," *Journal of Power Sources*. doi:10.1016/j.jpowsour.2021.229450.pp.1-22

Frenette, G. and Forthoffer, D. (2009) "Economic & commercial viability of hydrogen fuel cell vehicles from an automotive manufacturer perspective," *International Journal of Hydrogen Energy*. doi:10.1016/j.ijhydene.2009.02.072.pp.3579-3588

Greene, D.L., Ogden, J.M. and Lin, Z. (2020) “Challenges in the designing, planning and deployment of hydrogen refueling infrastructure for fuel cell electric vehicles,” *eTransportation*. doi:10.1016/j.etran.2020.100086.pp.1-22

Hames, Y. *et al.* (2018) “Analysis of the control strategies for fuel saving in the hydrogen fuel cell vehicles,” *International Journal of Hydrogen Energy*, 43(23). doi:10.1016/j.ijhydene.2017.12.150.pp.10811-10821

He, X. *et al.* (2021) “Well-to-wheels emissions, costs, and feedstock potentials for light-duty hydrogen fuel cell vehicles in China in 2017 and 2030,” *Renewable and Sustainable Energy Reviews*, 137. doi:10.1016/j.rser.2020.110477.pp.1-16

Hienuki, S. *et al.* (2021) “Environmental and energy life cycle analyses of passenger vehicle systems using fossil fuel-derived hydrogen,” *International Journal of Hydrogen Energy*, 46(73). doi:10.1016/j.ijhydene.2021.08.135.pp.36570-36580

International Energy Agency (2021). Hydrogen. https://www.iea.org/reports/hydrogen last retrieved on January 2,2022

Jack, U., de Souza, P. and Kalebaila, N. (2015) “Development of emergency response plans for community water systems,” *Water SA*, 41(2). doi:10.4314/wsa.v41i2.08.pp.37680-37696

Jones, J., Genovese, A. and Tob-Ogu, A. (2020) “Hydrogen vehicles in urban logistics: A total cost of ownership analysis and some policy implications,” *Renewable and Sustainable Energy Reviews*, 119. doi:10.1016/j.rser.2019.109595.pp.1-15

Kaya, K. and Hames, Y. (2019) “Two new control strategies: For hydrogen fuel saving and extend the life cycle in the hydrogen fuel cell vehicles,” *International Journal of Hydrogen Energy*, 44(34). doi:10.1016/j.ijhydene.2018.12.111.pp.18968-18980

Khan, U., Yamamoto, T. and Sato, H. (2020) “Consumer preferences for hydrogen fuel cell vehicles in Japan,” *Transportation Research Part D: Transport and Environment*, 87. doi:10.1016/j.trd.2020.102542.pp.1-17

Li, Y. and Kimura, S. (2021) “Economic competitiveness and environmental implications of hydrogen energy and fuel cell electric vehicles in ASEAN countries: The current and future scenarios,” *Energy Policy*, 148. doi:10.1016/j.enpol.2020.111980.pp.1-12

Li, Y. and Taghizadeh-Hesary, F. (2022) “The economic feasibility of green hydrogen and fuel cell electric vehicles for road transport in China,” *Energy Policy*, 160. doi:10.1016/j.enpol.2021.112703.pp.1-10

Liu, X. *et al.* (2020) “Comparison of well-to-wheels energy use and emissions of a hydrogen fuel cell electric vehicle relative to a conventional gasoline-powered internal combustion engine vehicle,” *International Journal of Hydrogen Energy*, 45(1). doi:10.1016/j.ijhydene.2019.10.192.pp.973-983

Manoharan, Y. *et al.* (2019) “Hydrogen fuel cell vehicles; Current status and future prospect,” *Applied Sciences (Switzerland)*. doi:10.3390/app9112296.pp.1-17

Murugan, A. *et al.* (2019) “Measurement challenges for hydrogen vehicles,” *International Journal of Hydrogen Energy*, 44(35). doi:10.1016/j.ijhydene.2019.03.190.pp.19327-19333

Nugroho, R. *et al.* (2021) “Cost of a potential hydrogen-refueling network for heavy-duty vehicles with long-haul application in Germany 2050,” *International Journal of Hydrogen Energy*, 46(71). doi:10.1016/j.ijhydene.2021.08.088.pp.35460-35478

Offer, G.J. *et al.* (2011) “Techno-economic and behavioral analysis of battery electric, hydrogen fuel cell and hybrid vehicles in a future sustainable road transport system in the UK,” *Energy Policy*, 39(4). doi:10.1016/j.enpol.2011.01.006.pp.1-28

Oldenbroek, V. *et al.* (2021) "Fuel cell electric vehicles and hydrogen balancing 100 percent renewable and integrated national transportation and energy systems," *Energy Conversion and Management: X*, 9. doi:10.1016/j.ecmx.2021.100077.pp.1-23

Park, S.Y., Kim, J.W. and Lee, D.H. (2011) "Development of a market penetration forecasting model for Hydrogen Fuel Cell Vehicles considering infrastructure and cost reduction effects," *Energy Policy*, 39(6). doi:10.1016/j.enpol.2011.03.021.pp.3308-3315

Ren, L., Zhou, S. and Ou, X. (2020) "Life-cycle energy consumption and greenhouse-gas emissions of hydrogen supply chains for fuel-cell vehicles in China," *Energy*, 209. doi:10.1016/j.energy.2020.118482.pp.1-21

Reverdiau, G. *et al.* (2021) "Will there be enough platinum for a large deployment of fuel cell electric vehicles?," *International Journal of Hydrogen Energy*, 46(79). doi:10.1016/j.ijhydene.2021.09.149.pp.39196-39207

Rizzi, F. *et al.* (2014) "Technological trajectories in the automotive industry: Are hydrogen technologies still a possibility?," *Journal of Cleaner Production*, 66. doi:10.1016/j.jclepro.2013.11.069.pp.329-336

Sagaria, S., Costa Neto, R. and Baptista, P. (2021) "Assessing the performance of vehicles powered by battery, fuel cell and ultra-capacitor: Application to light-duty vehicles and buses," *Energy Conversion and Management*, 229. doi:10.1016/j.enconman.2020.113767.pp.1-13

Schwoon, M. (2007) "A tool to optimize the initial distribution of hydrogen filling stations," *Transportation Research Part D: Transport and Environment*, 12(2). doi:10.1016/j.trd.2006.11.003.pp.71-82

Shelly, T.J. *et al.* (2021) "Comparative analysis of battery electric vehicle thermal management systems under long-range drive cycles," *Applied Thermal Engineering*, 198. doi:10.1016/j.applthermaleng.2021.117506.pp.25-29

Shin, J., Hwang, W.S. and Choi, H. (2019) "Can hydrogen fuel vehicles be a sustainable alternative on vehicle market?: Comparison of electric and hydrogen fuel cell vehicles," *Technological Forecasting and Social Change*, 143. doi:10.1016/j.techfore.2019.02.001.pp.240-248

Shusheng, X. *et al.* (2020) "Research and development of on-board hydrogen-producing fuel cell vehicles," *International Journal of Hydrogen Energy*, 45(35). doi:10.1016/j.ijhydene.2020.04.236.pp.17845-17857

Sinha, P. and Brophy, B. (2021) "Life cycle assessment of renewable hydrogen for fuel cell passenger vehicles in California," *Sustainable Energy Technologies and Assessments*, 45. doi:10.1016/j.seta.2021.101188.pp.2-8

Tamura, Y., Takabayashi, M. and Takeuchi, M. (2014) "The spread of fire from adjoining vehicles to a hydrogen fuel cell vehicle," in *International Journal of Hydrogen Energy*. doi:10.1016/j.ijhydene.2014.01.140.pp.6170-6175

Tanç, B. *et al.* (2019) "Overview of the next quarter century vision of hydrogen fuel cell electric vehicles," *International Journal of Hydrogen Energy*, 44(20). doi:10.1016/j.ijhydene.2018.10.112.pp.10121-10128

Ugurlu, A. (2020) "An emission analysis study of hydrogen powered vehicles," *International Journal of Hydrogen Energy*, 45(50). doi:10.1016/j.ijhydene.2020.05.156.pp.26523-26535

Wang, Q. *et al.* (2020) "Well-to-wheel analysis of energy consumption, greenhouse gas and air pollutants emissions of hydrogen fuel cell vehicle in China," *Journal of Cleaner Production*, 275. doi:10.1016/j.jclepro.2020.123061.pp.2-11

Watabe, A. and Leaver, J. (2021) "Comparative economic and environmental benefits of ownership of both new and used light duty hydrogen fuel cell vehicles in Japan," *International Journal of Hydrogen Energy*, 46(52). doi:10.1016/j.ijhydene.2021.05.141.pp.26583-26593

Wu, Y. *et al.* (2021) “Obstacle identification, analysis and solutions of hydrogen fuel cell vehicles for application in China under the carbon neutrality target,” *Energy Policy*, 159. doi:10.1016/j.enpol.2021.112643.pp.2-14

Wulf, C. *et al.* (2018) “Life Cycle Assessment of hydrogen transport and distribution options,” *Journal of Cleaner Production*, 199. doi:10.1016/j.jclepro.2018.07.180.pp.432-443

Xiong, H. *et al.* (2019) “An energy matching method for battery electric vehicle and hydrogen fuel cell vehicle based on source energy consumption rate,” *International Journal of Hydrogen Energy*, 44(56). doi:10.1016/j.ijhydene.2019.02.169.pp.29734-29742

Yartys, V.A. *et al.* (2021) “HYDRIDE4MOBILITY: An EU HORIZON 2020 project on hydrogen powered fuel cell utility vehicles using metal hydrides in hydrogen storage and refuelling systems,” *International Journal of Hydrogen Energy* [Preprint]. doi:10.1016/j.ijhydene.2021.01.190.pp.35897-35909

Zhang, C. *et al.* (2022) “Review on the safety analysis and protection strategies of fast filling hydrogen storage system for fuel cell vehicle application,” *Journal of Energy Storage*. doi:10.1016/j.est.2021.103451.pp.2-15

List of Figures

Page

Fig. 1: Fuel cell electric vehicles stock by region and by mode 25

Fig. 2: Fuel cell vehicles and hydrogen refueling station stock by region 27

List of Tables

Page

Table 1: Respondents of survey 49

Table 2: Characteristics of the respondents 50

Table 3: Correlation matrix between individual questions 51

Table 4: The Scale Statistics 52

Table 5: Statistics of individual questions 52

List of Abbreviations and Symbols

HFCV………………………..Hydrogen Fuel Cell Vehicles

HFCEV……………………...Hydrogen Fuel Cell Electric Vehicles

FCV…………………..…….. Fuel Cell Vehicles

FC……………………………Fuel Cell

EV……………………………Electric Vehicles

BEV…………………..……..Battery Electric Vehicles

PHEV………………………..Plug-In Hybrid Electric Vehicle

ICE…………………………..Internal Combustion Engine

H2……………………………Hydrogen

O2……………………………Oxygen

CO2………………………….Carbon dioxide

O2……………………………Oxygen

GHG………………………….Green House Gases

R&D………………………….Research and Development

ZEV………………………….Zero Emission