Journal of Electrotechnology, Electrical Engineering and Management (2025)
Clausius Scientific Press, Canada

DOI: 10.23977/jeeem.2025.080104
ISSN 2560-6697 Vol. 8 Num. 1

Key Technologies of Fuel Cells and Their Impact on New Energy Development

Yantong Ding*

School of Automobile Service Engineering, Shanghai Normal University Tianhua College, Shanghai, 201815, China

**Corresponding author: dingyantong@asu.edu.pl*

Keywords: Fuel cells, alternative energy, plug-in hybrids, transmission efficiency

Abstract: Fuel cells are considered to the best alternative to conventional batteries. By analyzing the different technical features of fuel cells compared to conventional batteries, we can determine whether fuel cells should be used as the primary source of electric power. It also analyzes the methods of using fuel cells for secondary use to better argue the advantages and disadvantages of fuel cells. Meanwhile, this paper also considers the application and cost of fuel cells to think about alternative methods of energy and their feasibility. We can also gain a complete understanding of the architecture of a fuel cell by examining its defects and the form of energy it produces. Therefore, fuel cells provide a cleaner, more efficient, and more energy-efficient power system for vehicles. In conclusion, fuel cells are highly likely to become the mainstream energy battery and power system. This article has drawn its conclusion that the title of the article should be standard based on different articles and reports.

1. Introduction

The essential of the fuel cells to Chinese vehicle market the background of the Chinese market’s the current situation. Currently, China's carbon dioxide emissions are entering a period of slow growth, and China has set clear targets of achieving "carbon peak" by 2030 and "carbon neutrality" by 2060. (September 22, 2020, the 75th session of the United Nations General Assembly, China). Before the 20th century, China's emissions increased, with the rate remaining relatively stable at around 5%. Since joining the WTO, carbon dioxide emissions have increased significantly. However, after 2011, the increase began to decline rapidly due to the protection of policies, and it remained below 5% [1]. However, excessive emissions of carbon dioxide can lead to warming, and the "dual carbon" plan has also become a major goal for China's development [2]. This plan indicates that China is confident of achieving carbon peak in 2023, with a peak value of 17.3×108t. At the same time, relative to BAU emissions are reduced 1.19×108, the contribution rate is approximately 44% [3]. Carbon neutrality requires achieving net-zero emissions, which means reducing emissions to more than 90%, reduce the remaining emissions by less than 10% to align with the 1.5 ℃ target [4]. However, this solution is not perfect either, as there are issues that need to be addressed, such as the weight, capacity, emissions, and charging efficiency of the battery. In the long run, hydrogen fuel cell electric vehicles are the best solution to address these problems. Researchers aim to increase the likelihood of load by integrating fluctuating renewable energy, which is the core technology of fuel cells, into fuel cell vehicles' charging and network nodes, in harmony with distribution facilities. Fuel cells are used in vehicles to act as a storage container for converting electrical energy into mechanical energy using liquid or gaseous fuels as the power source. This study can extend the electric energy reserve of new energy vehicles and improve the transmission efficiency of the vehicles. According to studies, fuel cell vehicles do not require as much space to accommodate the power system, and their range per charge can be about 160 kilometres higher than that of conventional battery vehicles, which is the main reason why research into fuel cells is so popular. Carbon emissions can be reduced by up to 56.33%–103.14% or 0.64 Gt to 0.006 Gt by using fuel cells. In other words, with the continuous changes in policy technology and infrastructure, the environment for human survival can be further improved. This requires cooperation and win-win situation among all countries to break down technological barriers, improve fuel cell performance, break monopolies, and reduce costs [5]. The United States has conducted commercial collaborations on this project, such as using enough hydrogen storage to propel a 127-ton locomotive [6]. This article examines the impact of technological advancements in fuel cells on the new energy vehicle industry, based on the structure of fuel cells and a comparison with conventional batteries. It also analyses the recycling and utilization of batteries.

2. Technological innovation for fuel cells (Innovative technology and how to achieve it)

Hydrofluorocarbons are often considered a versatile alternative energy source that can support additional electricity from distributed energy sources. The design of the fuel cell system allows it to adjust the power ratio according to the type of fuel, operating temperature, and performance of the electrolyte. Any fuel cell can store very powerful electrical energy, as shown in the table 1. Common types of fuel cells include proton exchange membrane fuel cells, solid oxide fuel cells, direct methanol fuel cells, alkaline fuel cells, molten carbonate fuel cells, and phosphoric acid fuel cells. Table 2 classifies fuel cells into solid, liquid, and gaseous types. Solid fuel cells are powered by biological reactions of bacteria to generate electricity. These low-temperature fuel cells are divided into mediated and non-mediated types. Intermediation refers to the movement of electrons from the fuel in a fuel cell to the anode, while non-intermediation involves the direct transfer of electrons from the fuel to the anode through a chemically active, reductase protein. Meanwhile, liquid fuel cells and gas fuel cells can make the battery lighter and lower in power consumption. It is evident that the automotive industry will invest more deeply in research and development of fuel cell size, weight, energy density, and efficiency [7].

Table 1: Typical values and properties of existing FC structures [7].

Typical Values	PEMFC	SOFC	DMFC	AFC	MCFC	PAFC
Electrolyte	Polymer membrane	Ceramic	Polymer membrane	Potassium hydroxide	Molten carbonate	Phosphoric acid
Fuel	Pure H_2	H_2, CO, CH_4	CH_3OH	Pure H_2	H_2, CO, CH_4	Pure H_2
Cell voltage (V)	~1.1 V	0.8–1 V	0.2–0.4 V	~1 V	0.7–1 V	~1.1 V
Efficiency (%)	40–60 %	50–70 %	20–40 %	60–70 %	~50–70 %	~40–55 %
Operating Temperature	<100 ◦C	600–1000 ◦C	90–120 ◦C	65–220 ◦C	620–660 ◦C	150–200 ◦C
Power rating	10 W–500 kW	1 kW–2 MW	1 W–1 kW	10–200 kW	10 kW–200 MW	200 kW–50 MW

Table 2: Future FC structures according to fuel type [7].

Future FC Structures				
Solid Fuels		Liquid Fuels		Gaseous Fuels
Microbial FCs	Direct Carbon FCS	Synthetic fuels	Biofuels	Direct reaction of non-hydrogen based fuels
* Mediated	*DCMCFC	*Methanol	*Ethanol	*Ammonia
Unmediated	*DCSOFC			

3. How does the innovation of the fuel cells influence new energy vehicles

One of the convenient aspects of fuel cell vehicles is that different fuels can be chosen for different regions. This study can reduce the consumption of conventional fuels and reduce emissions, ultimately becoming a carbon-free mode of transportation. Fuel cell vehicles can reduce greenhouse gas emissions by 80% while also increasing the efficiency of vehicle transmission. Next, we will elaborate on the phenomenon of this study from the perspectives of advantages, disadvantages, security, and charging methods.

3.1. Comparison of fuel cells and conventional batteries

The energy of a fuel cell comes from different types of fuels stored in the vehicle, while the energy of the battery comes from charging the battery by the grid, which is the biggest difference between the two types of vehicles. These renewable fuels can help better control urban air pollution and improve the control and performance of vehicles.

3.1.1. Battery weight

The composition of a fuel cell vehicle includes a hydrogen tank, a high-power battery pack used to capture regenerative braking and acceleration, a fuel cell stack, and all auxiliary fuel cell system components. For fuel cells, the battery pack can store up to 200 watt-hours per kilogram of energy, while most new energy vehicles can only store 100 to 150 watt-hours per kilogram. This represents that fuel cells can store more practically useful energy, rather than just the volume of energy stored. It also proves that fuel cells can generate more electricity in a smaller volume. For hybrid vehicles, a light fuel cell only requires a slightly larger fuel tank to extend its range, and the added fuel cell mass is very small, which also leads to a significant reduction in the overall weight of the hybrid vehicle.

3.1.2. Battery storage

All research indicates that hydrogen tanks occupy more space than fuel tanks, but compressed hydrogen tanks and fuel cells together can be more practical than energy batteries in terms of space usage, with energy density almost equivalent to advanced lithium-ion batteries with a pressure of 35 megapascals. Therefore, a General Electric vehicle needs more onboard energy storage to travel a longer distance, although they have similar energy density, but a conventional battery car needs more space. In general, lead-acid batteries are not suitable for five-seat cars with a range of more than 60 kilometers, while fuel cell vehicles can travel up to 240 kilometers under the same working conditions.

3.1.3. Charging efficiency

Current high-pressure natural gas vehicles use a high-pressure hydrogen refueling system for refueling, which, after calculation, takes an average of 3.3 minutes per individual refueling event, 16,300 times. The technical problem that fuel cells currently face is whether they can manufacture batteries that can be quickly charged like regular batteries without overheating and destroying the battery, causing an imbalance in the voltage balance. The charging efficiency of a fuel cell can be much higher than that of a regular battery, typically saving half an hour to an hour of charging time. Table 3 provides an explanation of the minimum charging times for electric and fuel cell vehicles.

3.1.4. Impact of environment

Currently, the world's electricity is mainly derived from coal, and the efficiency of the grid is relatively low. If it is possible to increase the proportion of fuel cells used in vehicles by transforming hydrogen in the next 10 to 20 years. At the same time, there is a carbon tax and cap on carbon dioxide emissions, as well as the introduction of trade regulations, which will reduce the carbon footprint of the grid, which will take 10 to 20 years for governments and power plants to match with capture and storage systems that can be replaced by renewable energy. The power plant is currently able to convert only 32% to 36% of the energy in coal into electricity, while also incurring an 8% loss during transmission to the destination. Under the same conditions, fuel cell vehicles would emit less greenhouse gases than conventional battery vehicles, and they can even achieve longer driving ranges. Compared to traditional gasoline cars, fuel cell vehicles that use natural gas to produce hydrogen fuel can reduce greenhouse gas emissions by about 47%.

Table 3: Estimated minimum fueling time for battery EVs and fuel cell EVs [8].

Battery electric vehicles						Fuel cell EVs
Vehicle range (km)	Energy required from grid (kWh)	Level 1 charging time (hours) 120 V, 20 A 1.9 kW	Level II charging time (hours) 240 V, 40 A 7.7 kW	Level III charging time (hours) 480 V, 3φ		Hydrogen tank filling time (hours)
				60 kW	150 kW	
241	56	29.2	7.3	0.9	0.4	0.08
322	82	42.7	10.68	1.4	0.55	0.10
483	149	77.6	19.40	2.5	0.99	0.15

3.1.5. Expansibility

Although pure fuel cell vehicles are more expensive than traditional vehicles and conventional battery vehicles, fuel cell plug-in hybrids are only about $6,000 more expensive than traditional gasoline vehicles, while conventional battery vehicles are about $19,500 more expensive than gasoline vehicles. Once government agencies can invest in fuel gas and once the key components of fuel cells are in place, the batteries can provide a strong return for the new energy vehicle industry while allowing users to charge during off-peak hours [8].

3.2. Fuel cells' defects

Defects in fuel cells can be beneficial at the microscopic level in improving fuel cell performance, and this section will discuss fuel cell defects from the perspective of their classification features and fundamental principles.

3.2.1. Classification and characteristic

Defects can be classified as bulk defects and surface defects, and the defects of fuel cells include point defects, line defects, and surface defects. These defects are used to adjust the electronic structure and surface interface properties with the help of electrocatalysts. When impurity particles replace normal atomic particles and occupy gaps in normal nodes, a doping defect occurs. Defects can lead to diversity and complexity in fuel cells.

There are several methods for studying the effects and location of electrocatalyst defects, including X-ray absorption spectroscopy with aberration correction, transmission electron microscopy with electron replica Raman spectroscopy, X-ray color or scattering patterns, photocurrent spectroscopy, electron-annihilation lifetime spectroscopy, electron paramagnetic resonance spectroscopy, and high-angle annular dark-field scanning transmission electron microscopy. The structure of these defects can be observed by comparing the morphology of concave cubic nanocrystals with or without defects. Defective electrocatalysts have more edge sites because they disrupt the original crystal structure, while increasing or decreasing the crystal size of the nanomaterial. Of course, it will also be necessary to fully utilize representation methods in the future to study fundamental and systemic defects.

3.2.2. Structure

Existing electrocatalysts are manufactured by remoting integration distribution of Pt nanowires with a macrophage-shaped structure. Studies have shown that ionizing radiation can be used to detect defective nanoparticles as electrocatalysts for oxidation reactions and ethanol oxidation reactions. Etching is usually the most direct and effective method, which includes wet etching, acid etching, reductive etching, plasma etching, and high-energy plasma etching. We can use nanomaterials consisting of transition metal compounds split into bimetallic hydroxides and organic metal frameworks to detect defects. With the development of these synthetic defects, the sustainable development of catalysts can continue to be maintained.

3.2.3. Comprehend

The evolution of electrocatalyst theory and experiment has led people to pay increasing attention to the properties and electronic structure of catalysts. Its reaction rate is related to the adsorption energy and the specific catalytic process' reaction pathway, which may be affected by the adsorption strength of the reaction intermediates and products. The pentagonal carbon defect with a Z-shaped edge can adjust the electronic configuration of neighboring carbon atoms and promote catalytic reactions. Nitrogen vacancies in carbon nitride catalysts promote the chemical of N_2, while the electronic structure can activate N_2. Therefore, in terms of structure, the relationship between defect engineering and electrocatalytic ability is of great importance, but this engineering is still a difficult problem for humans to precisely identify and understand.

3.3. Fuel cells’ security

Due to the rising cost of traditional fossil fuels, supply chain shortages caused by social issues globally, and the international focus on global warming, cars need to transition to electrification. For fuel cells, these problems no longer exist. However, fuel cells currently lack validation in terms of safety, which may be one of the reasons why automakers are hesitant to use fuel cells extensively as part of their vehicle propulsion systems.

3.3.1. Prevent failure

Power failure is a common fault in fuel cells, so battery manufacturers need to prevent such situations from occurring from the root. The operating conditions of a fuel cell are similar to those of a generator, which can minimize power supply interruptions to the greatest extent possible. Therefore, it will become a very popular power source for automobiles. However, these fuel cells are also subject to potential threats from harsh working environments and insufficient chemical reactions of the fuel. To make fuel cells operate more stably, it is necessary to improve the safety of fuel sources, completely release the harmless gas produced by the fuel into the air and combine it with other energy forms to improve its power generation efficiency [9].

3.3.2. Offer cheaper and cleaner solutions

Fuel cells are structurally different from traditional internal combustion engines and conventional batteries, as they do not rely on mechanical parts for the chemical energy to be converted into motion. Therefore, fuel cells are generally more efficient than the alternatives. However, the fuel for fuel cells is more dependent on the technology of some technologically advanced nations for all countries, and using these technologies comes with a certain cost. So far, the United States has been able to use fuel cells for military purposes and provide emergency power and primary power [10].

3.4. Charging for vehicles

Hybrid fuel cell vehicles can improve the transmission efficiency of the vehicle, which can utilize the motor to store power and recover energy during braking. This section evaluates the performance of fuel cell vehicles by analyzing test data and assessing the battery function, charging maintenance, and design of fuel cell vehicles. It also examines the characteristics and technologies of battery components.

3.4.1. Energy storage requirements

The size of the energy storage unit must be large enough to store enough energy to provide the vehicle with sufficient peak power, which can improve the vehicle's acceleration performance and driving cycle while also increasing its range. Users are increasingly demanding that their vehicles have sufficient lifespan and range, although these are merely basic performance requirements for automobiles. However, in fuel cell vehicles, there are more stringent requirements placed on the weight, volume, and cost of energy storage, which can limit the low cost and high sales volume of the vehicles. The size of the energy storage unit is adjusted according to the required power, and it is generally within the specified range of vehicle dimensions. The weight and volume can be changed to affect energy consumption, test cycles, and the ease of achieving the required performance in terms of energy density. The size and weight of a battery are primarily determined by its pulse power density. Therefore, to create high-power hybrid vehicles, fuel cells in automotive fuel cells need to support the engine in operation, in which case the volume of the energy storage unit can be optimized for the most economical situation.

3.4.2. Technical support

Supercapacitors currently use carbon-carbon double-layer devices as their commercialized technology. For most high-power battery development, a high-energy density battery is not the ultimate answer, as mentioned in previous articles, the battery size is adjusted according to the power requirements, so the requirement for energy density is not as high. The development of plug-in hybrids is much less extensive, but their performance lies somewhere between that of electric vehicles and pure fuel cell vehicles, as shown in Table 4. In general, fuel cell information is updated more frequently and rapidly than that of traditional batteries, so companies are often developing corresponding technologies for fuel cells. The power of a fuel cell can be much higher than that of a conventional battery, while being lighter and more efficient. Its high-power capability requires a lower resistance in the battery. Fuel cells are designed for deep discharge, long cycle life batteries, so they do not take shallow discharge like traditional batteries, therefore they have the characteristic of higher energy density. The goal of fuel cells is to achieve high power density discharge, which is at least five watts per kilogram, and its lifespan requires at least 50,000 deep discharge cycles. In this way, the efficiency of the fuel cell can be fully released [11].

Table 4: Characteristics of Various Technologies/Types of Batteries for Use in Vehicle Applications (EV and HEV) [11].

Battery technology	Applic. type	Ah	V	Wh/kg At C/3	Resist mOhm	W/kg Match. Imped.	W/kg 95%eff	Useable SOC,
Lead-acid								
Panasonic	HEV	25	12	26.3	7.8	389	77	28%
Panasonic	EV	60	12	34.2	6.9	250	47	--
Nickel Metal Hydride								
Panasonic EV	EV	65	12	68	8.7	240	46	--
Panasonic HEV	HEV	6.5	7.2	46	11.4	1093	207	40%
Ovonic	EV	85	13	68	10	200	40	--
Ovonic	HEV	12	12	45	10	1000	195	30%
Saft	HEV	14	1.2	47	1.1	900	172	30%
Lithium-ion								
Saft	HEV	12	4	77	7.0	1550	256	20%
Saft	EV	41	4	140	8.0	476	90	--
Shin-Kobe	EV	90	4	105	.93	1344	255	--
Shin-Kobe	HEV	4	4	56	3.4	3920	745	18%

4. The advantage and improvement of the fuel cells innovation

Due to the increasing number of new energy vehicles on the road, this trend has led to an increasing demand for batteries, which also raises the question of how to handle these batteries when their lifespan comes to an end. For fuel cells, the same situation will arise in the future, and if these batteries are not properly disposed of, they can have irreversible effects on the environment. Batteries can be recycled and reused, thus reducing the need for new battery production. This will allow these fuel cells to have a second life, which will become part of the global circular economy strategy.

4.1. Battery reuse and recycling

The energy storage system for fuel cells can be divided into two groups, the first of which is oriented towards power generation and grid distribution, and the second of which tends to take a user-level perspective. Batteries can be recycled and reused, thus reducing the need for new battery production. This will allow these fuel cells to have a second life, which will become part of the global circular economy strategy.

4.1.1. Reuse

The scale of the installation depends on the user's level, some of which require fast response times, while others do not. At times, they need to be able to deliver multiple energy streams simultaneously, while at other times, they only need support for a few minutes. The availability of raw material batteries is not dependent on the manufacturer's decision, so the average person can obtain a higher extraction rate from secondary batteries. For these fuel cells, safety is of great significance, as the cells are subject to aging and short circuits, so not all cells can be reused. Meanwhile, since fuel cells are smaller than traditional batteries, they can be reused by individually controlling the structural batteries and focusing on some fuel cells that store energy from charging. The electric control system of the vehicle can allow the vehicle to monitor the health of each battery and provide users with the time for maintenance and replacement to keep the fuel cell in optimal working condition.

There are two possible trends for the reuse of these batteries: direct reuse and module disassembly. Direct reuse provides a lower cost for fuel cells, but direct reuse, due to stacking issues, lacks adaptability in module removal, which is a more universal solution that can transform its system volume. Removing the battery maximizes the possibility and reduces the unevenness of the battery, but the cost will rise significantly. Batteries are playing a strategic role, offering European battery manufacturers an opportunity to expand into new markets. As shown in Figure 1, this is the market share of most electric vehicles, which determines different trends in how different countries will address battery aging in the future.

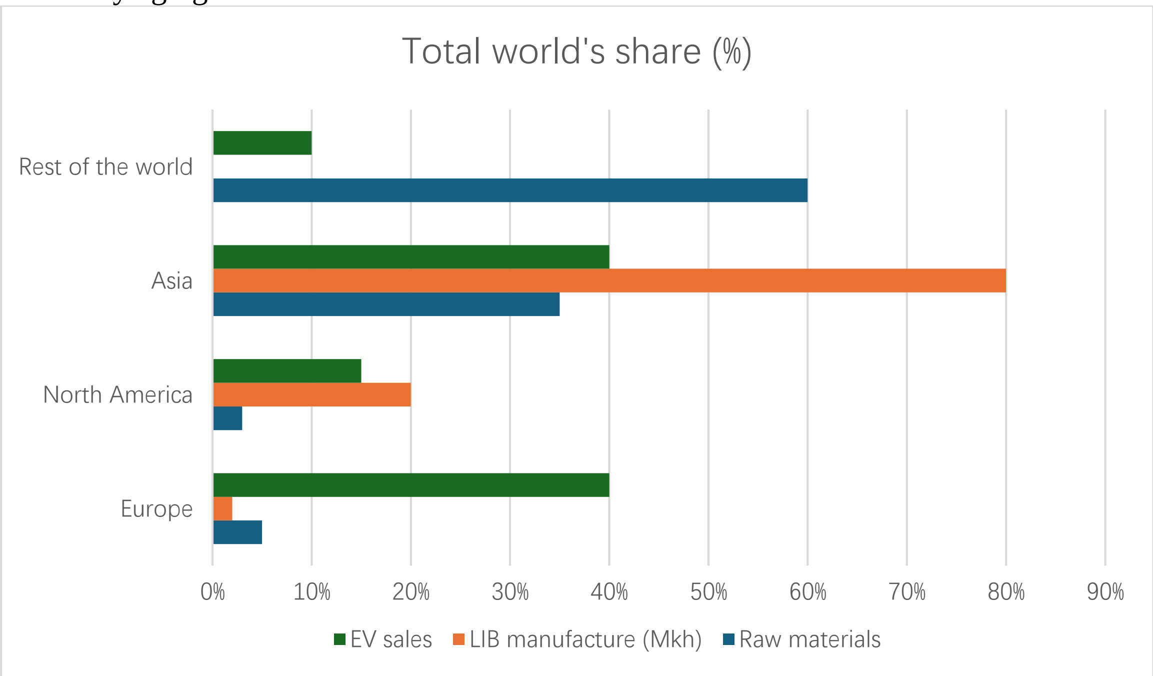

Figure 1: Percentage of electric vehicle (EV) world sales [12].

4.1.2. Recycling

The recycling of fuel cells has a very significant impact on both ecological and economic aspects, as it allows for continued use of the fuel cells after they have been discarded, especially the metals nickel and platinum found in fuel cells can drive the recycling process. If the recycling process is not carried out, your demand will be greater, and the total amount of extraction will not meet your needs. Thermal metallurgy/smelting and hydrogen metal lubrication can be used separately or in combination with each other. These chemical components are separated through several stages, such as precipitating the solvent, extracting with ion exchange, and electrolytic extraction. Compared to other processes, it can save up to 51.3% of the materials used in battery manufacturing. Meanwhile, carbon dioxide emissions and energy consumption can be reduced by 70%. There are also other processes that not only recover high-value metals or CRMs, but also produce a byproduct in the form of salts from battery components. This is a mechanical process where the batteries are electrolytically separated and then broken down into concentrated metals to avoid thermal separation. The batteries can be cooled to -175 ℃ by liquid nitrogen, an inert gas. Another process combines mechanical and chemical recycling of lithium-ion batteries. The batteries are cut up in an inert gas atmosphere and then pulverized, resulting in a product rich in metal oxide-carbon magnetic compounds. Mechanical separation liquids can be used in portable containers at a given location to solve the problem of separating existing components.

4.2. The advantage of the fuel cells innovation on the new energy vehicles

The economic benefits of fuel cells have decreased from over €600 per kilowatt-hour in 2010 to only €270 per kilowatt-hour in 2015 and are expected to trend towards less than €100 per kilowatt-hour in the future. Such research not only saves manufacturers' production costs, but also reduces the cost that customers need to maintain the battery and purchase. By 2030, its price may be less than three times that of a conventional battery, making it more competitive in the market, and automakers no longer need to compare its cost with that of traditional batteries. The demand and availability of fuel cell vehicles are the main factors directly affecting the rise or fall of manufacturing costs, so it is very necessary to study the aging of batteries and observe whether there are economic effects.

4.3. The improvement and influence of the fuel cells innovation. (Most about new energy vehicle)

The development of electric vehicles in the market should combine the concept of recycling, meaning that at its core, it is a circular economy. The development of infrastructure for recycling electric vehicle batteries will further solidify the handling of aging fuel cells. The lifespan of fuel cells is limited by the operating conditions, so further research is needed to analyze different application scenarios in various fields to find new recycling technologies. For example, identifying the source of batteries and conducting battery testing can help avoid the use of low-recycled, aging batteries for reuse. It is also a good method to remove the battery from the fuel cell and isolate some of the compartments, as well as disassemble the battery components, which is also very safe. Of course, this disassembly of the battery can only be done at a recycling facility [12,13].

5. Conclusion

This article explains how and why fuel cells are developing in the field of new energy vehicles by describing their technical features. The fuel forms and structures of alternative energy sources were analyzed, as well as how fuel cells can reduce greenhouse gas emissions. Meanwhile, this paper also provides a detailed discussion on the recycling and utilization of future fuel cells. Research into fuel cells is a trend for car manufacturers and battery manufacturers for the future, as fuel cells can be more efficiently and widely applied in the automotive market. In the future, Chinese automakers can use fuel cells to achieve the targeted results of the "Dual Carbon" plan. By transitioning traditional power generation methods to secondary energy generation, fuel cell vehicles can be provided with a sustainable opportunity. Ultimately, it can reduce carbon footprint by about 31% and further reduce carbon dioxide emissions.

References

[1] He Shifei. "China's carbon dioxide emissions are entering a period of slow growth."[N]. International Business, 2022-08-17(004).

[2] Lu Yanwen. "Investigation of Effective Measures for Achieving Carbon Neutrality Based on Ecosystem Carbon Cycle." [J]. Resources Economization & Environmental, 2024, (09):144-147.

[3] Pang Lingyun, Wen Hui, Chang Jing, et al. "Pathway of Carbon Emission Peak for China's Petrochemical and Chemical Industries." [J]. Research of Environmental Sciences, 2022, 35(02):356-367.

[4] "The Net-Zero Standard". Science Based Targets. Retrieved 2023-12-13.

[5] Zahoor, Aqib, et al. "Can the new energy vehicles (NEVs) and power battery industry help China to meet the carbon neutrality goal before 2060?" Journal of environmental management 336 (2023): 117663.

[6] Gambuti, Raffaele, et al. "Electric vehicle trip planning integrating range constraints and charging facilities." 2015 23rd Mediterranean Conference on Control and Automation (MED). IEEE, 2015.

[7] Akinyele, D. O., and R. K. Rayudu. "Sustainable energy technologies and assessments." Review of energy storage technologies for sustainable power networks 8 (2014): 2213-1388.

[8] Thomas, C. E. "Fuel cell and battery electric vehicles compared." international journal of hydrogen energy 34.15 (2009): 6005-6020.

[9] Li, Wei, et al. "Defect engineering for fuel-cell electrocatalysts." Advanced Materials 32.19 (2020): 1907879.

[10] Fuel Cells for Energy Security Published Dec. 3, 2012

[11] https://www.erdc.usace.army.mil/Media/Fact-Sheets/Fact-Sheet-Article-View/Article/476732/

[12] Burke, Andrew F. "Batteries and ultracapacitors for electric, hybrid, and fuel cell vehicles." Proceedings of the IEEE 95.4 (2007): 806-820.

[13] Kotak, Yash, et al. "End of electric vehicle batteries: Reuse vs. recycle." Energies 14.8 (2021): 2217.