Frontiers in Health Informatics
ISSN-Online: 2676-7104
www.healthinformaticsjournal.com
2024; Vol 13: Issue 7
Open Access

A Comparative Review of Hydrogen Fuel Cell and Lithium Battery: Environmental and Health Impacts

Shweta Y Prajapati[1],Dharmesh Patel[2],Yogesh Prajapati[3],Dr. Jatinkumar J. Patel[4],Himani Dalwadi[5]
[1]Research scholar Gujarat Technological University Syp.ee7@gmail.com
[2]Assistant Professor Electrical Engineering Department Government Engineering College Bharuch
[3]Assistant Professor Electrical Engineering Department Birla Vishvakarma Mahavidyalaya Engineering College Vallabh Vidyanagar yrprajapati@bvmengineering.ac.in
[4]Professor Electrical Engineering Department HCET, Gokul University jjpatelgcet@gmail.com
[5]Assistant Professor Electrical Engineering Department Birla Vishvakarma Mahavidyalaya Engineering CollegeVallabh Vidyanagar himani.dalvadi@bvmengineering.ac.in

Cite this paper as: Shweta Y Prajapati,Dharmesh Patel,Yogesh Prajapati,Dr. Jatinkumar J. Patel,Himani Dalwadi (2024). A Comparative Review of Hydrogen Fuel Cell and Lithium Battery: Environmental and Health Impacts. *Frontiers in Health Informatics*, *13 (7) 561-571*

Abstract
The utilization of fossil fuels in transportation releases substantial quantities of greenhouse gases, which contribute to the phenomenon of global warming, air pollution, and health concerns. Research indicates that vehicles alone discharge over a million tons of carbon dioxide into the atmosphere annually due to their internal combustion engines that rely on fossil fuels. In contrast, electric vehicles do not emit any pollutants from their exhaust pipes. Consequently, governments worldwide are actively striving to substitute fossil fuel vehicles with electric automobiles. Battery-powered and hydrogen fuel cell electric cars are two feasible alternatives to internal combustion engines. This investigation examines the fundamental functionalities and recent advancements of battery-powered and hydrogen fuel cell electric cars. A comprehensive evaluation of the pros and cons of each technology is presented. Moreover, in this study, we will compare Lithium-Ion Battery (LIB) and Hydrogen Fuel Cell (HFC) technologies. The criteria such as energy and power capabilities, efficiency, lifetime, cost, recyclability, and safety are compared. By evaluating these factors, it can make informed decisions on the implementation of these technologies.
Keywords: Green Energy, Hydrogen Fuel Cell, Lithium Battery, Human Health

I. Introduction:

It is crucial to make clear that lithium-ion battery storage and green hydrogen have various uses and are not always in direct competition [1]. With their respective advantages and uses, green hydrogen and lithium-ion storage can work in tandem to help us move to a sustainable energy future. Here are some things to think about in terms of how green hydrogen may complement lithium-ion storage rather than replace it [2]. Weighing a variety of criteria, such as market trends, infrastructure development, environmental effects, and technology improvements, is necessary to determine the future of electric cars (EVs). There are benefits and drawbacks to both hydrogen fuel cell cars (FCVs) [3] and battery electric vehicles (BEVs). Thanks to improvements in battery technology, which have led to greater ranges, quicker charging periods, and lower costs, battery electric cars have become increasingly popular in recent years[4]. With several nations investing in charging networks to meet the rising demand, the infrastructure for BEVs is likewise increasing quickly. Furthermore, BEVs have zero tailpipe emissions, which makes them ecologically benign—especially when they run on renewable energy. Conversely, hydrogen fuel cell cars use hydrogen gas to react chemically with oxygen to generate electricity; the only waste they release is water vapours [5]. When comparing FCVs to BEVs, FCVs provide faster refuelling times and greater range. Nevertheless, there are several obstacles to overcome in the process of producing, storing, and distributing hydrogen, such as expensive production and conversion costs, inadequate infrastructure, and efficiency losses [6].

The eventual domination of either technology will ultimately rely on several variables, such as government regulations, infrastructural development, customer preferences, industry investments, and technological breakthroughs. Though BEVs currently enjoy a greater degree of market acceptance and infrastructure advantages, future developments in hydrogen technology and infrastructure may tip the scales in favour of BEVs, particularly in industries where long-range and fast refuelling are essential, like heavy-duty transportation. Both technologies will probably exist side by side and enhance one another in the developing field of environmentally friendly transportation. Lithium-ion storage and green hydrogen can frequently complement one another. For example, during times of abundant power, excess renewable energy may be utilized to electrolyze hydrogen, which can then be stored and converted back to electricity when needed[7].

II. Comparison according to the working principle

Fig. 1 and Fig. 2 represent the structure of the fuel cell and lithium battery respectively.

<table>
<tr><th>Hydrogen fuel cell</th><th>Lithium battery</th></tr>
<tr><td>
A fuel cell is a device that transforms chemical energy into electrical energy. As shown in Fig.1 the fuel cells are like batteries in that they require a constant supply of fuel, often hydrogen. They will continue to generate energy as long as fuel remains accessible. Hydrogen fuel cells have been used to power satellites, space capsules, cars, watercraft, and submarines.

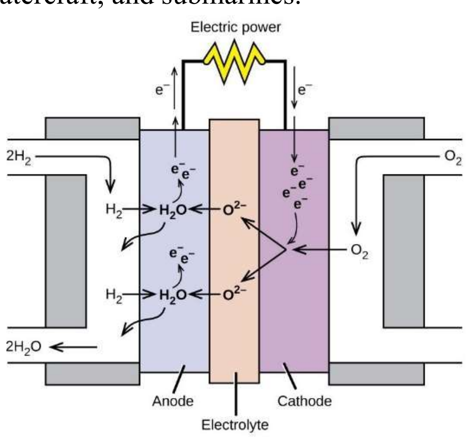

Fig. 1 Hydrogen Fuel Cell

In a hydrogen fuel cell, the reactions are
Anode:$2H_2+2O^{2-}\longrightarrow 2H_2O+4e^-$
Cathode:$O_2+4e^-\longrightarrow 2O^{2-}$
Overall:$2H_2+O_2\longrightarrow 2H_2O$
The voltage is around 0.9 V. Fuel cells generally have an efficiency of 40% to 60%, which is greater than the normal internal combustion engine (25% to 35%), and, in the
</td><td>
Batteries are galvanic cells, or a series of cells, that generate electricity. When cells are united to form batteries, their potential is an integer multiple of that of a single cell. As seen in Fig. 2, rechargeable lithium batteries are utilized in a variety of portable electronic gadgets.

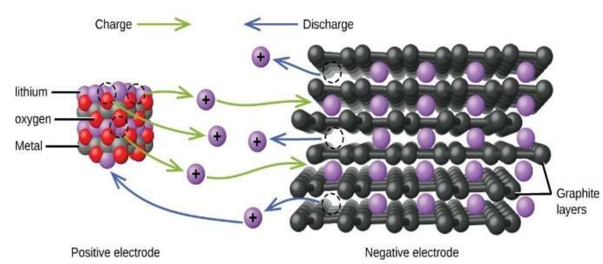

Fig. 2 Lithium Battery

The reactions are:
Anode: $LiCoO_2\rightleftharpoons Li_{x-1}CoO_2+xLi^++xe^-$
Cathode: $xLi^++xe^-+xC_6\rightleftharpoons xLiC_6$
Overall: $LiCoO_2+xC_6\rightleftharpoons Li_{x-1}CoO_2+xLiC_6$
With the coefficients denoting moles, x is only approximately 0.5 moles. The battery voltage is around 3.7 volts. Lithium batteries are popular because they can deliver a high current, are lighter than equivalent batteries of other types, create a fairly constant voltage as they drain, and lose charge gradually when stored.
</td></tr>
</table>

case of the hydrogen fuel cell, create only water as exhaust. Currently, fuel cells are relatively costly and have problems that lead them to fail after a short period.	
Working Principle: An apparatus for producing electricity that directly transforms the chemical energy of hydrogen and oxygen is a hydrogen fuel cell. The fundamental idea is the reversed reaction of water electrolysis, which gives the anode and cathode, respectively, hydrogen and oxygen. After reacting with the electrolyte as it diffuses outward via the anode, hydrogen releases electrons that travel through the external load to the cathode. The car's electric engine runs on hydrogen fuel, which is kept in an energy storage tank. Hydrogen fuel reacts with oxygen in the surrounding air to produce electricity. When hydrogen is created using renewable energy sources, the entire cycle emits no hazardous pollutants, making hydrogen energy fuel cells environmentally friendly[8].	**Working Principle:** A lithium battery is a rechargeable battery that functions primarily by transporting lithium ions between the positive and negative electrodes. When charged, lithium ions are de-embedded from the positive electrode and immersed in the negative electrode via the electrolyte, which is lithium-rich; when discharged, the opposite occurs. When charging, the more lithium ions embedded in the negative electrode, the greater the charging capacity; when discharging, the lithium ions embedded in the negative electrode's carbon layer are freed and returned to the positive electrode. The discharge capacity increases as more lithium ions return to the positive electrode[9].

III. Comparison According to a Greener Future:

Both lithium-ion batteries and hydrogen fuel cells have crucial roles in the development of a more sustainable future, as they facilitate cleaner energy storage and transportation[10].

Parameter	Hydrogen Fuel Cell	Lithium Battery
According to the Area of application	Hydrogen fuel cells present an alternative electrification approach, particularly beneficial for situations necessitating long-range travel and rapid refuelling, such as heavy-duty transportation and specific industrial processes [11]. By converting hydrogen and oxygen into electricity, fuel cells generate water vapor as the sole byproduct, establishing them as a zero-emission technology. Although obstacles persist in hydrogen production, storage, and distribution, efforts are underway to enhance efficiency and decrease costs, spurring interest in fuel cell vehicles and stationary power applications.	Lithium-ion batteries find extensive application across various sectors, including portable electronics, electric vehicles (EVs), and renewable energy storage. They boast a remarkable energy density, and prolonged cycle life, and demand relatively less maintenance when compared to conventional lead-acid batteries. In the context of EVs, lithium-ion batteries play a pivotal role in curbing greenhouse gas emissions by substituting internal combustion engines with electric powertrains. Furthermore, when coupled with renewable energy sources like solar and wind, lithium-ion batteries enable the storage of intermittent energy, thereby contributing to grid stability and reducing reliance on fossil fuels [12].

According to the capability	In contrast, hydrogen fuel cells provide distinct advantages for situations that necessitate long-range capabilities and swift refuelling, such as heavy-duty trucks, buses, and potentially even the marine and aviation sectors [13].	In a future that prioritizes sustainability, it is likely that both lithium-ion batteries and hydrogen fuel cells will coexist, serving specific purposes and complementing each other's strengths. Lithium-ion batteries excel in applications that demand high energy density and versatility, such as portable electronic devices and EVs with shorter to medium-range capabilities [14].

Ultimately, a combination of these technologies, along with continued advancements in renewable energy generation and energy efficiency, will contribute to a more sustainable and environmentally friendly energy landscape.

IV. Comparison according to characteristics and applications:

Hydrogen fuel cells and lithium batteries are both used for energy storage [15] and have different characteristics and applications. Here are some key differences between the two.

Parameters	**Hydrogen Fuel Cell**	**Lithium Battery**
Energy Storage Mechanism	By means of an electrochemical reaction, the chemical energy derived from hydrogen and oxygen is converted into electricity. This process entails the combination of hydrogen, which is usually stored in tanks, with oxygen from the air. Consequently, electricity is produced, and water and heat are generated as byproducts[16].	By facilitating the movement of lithium ions between the positive and negative electrodes, the battery effectively stores energy in the form of chemical energy[17]. During the charging process, the lithium ions travel from the positive electrode to the negative electrode. Conversely, when the battery is discharged, the lithium ions retrace their path back to the positive electrode.
Energy Storage vs. Energy Carrier:	Green hydrogen is commonly viewed as an energy carrier that stores energy in the form of hydrogen gas. This stored energy can be utilized for various purposes such as electricity generation, fuel cell vehicles, and industrial processes [14].	Lithium-ion batteries are predominantly utilized for energy storage, storing electrical energy for future use across various applications such as electric vehicles (EVs), grid storage, and backup power [18].
Intermittency and Long-Term Storage	Green hydrogen proves to be more suitable for long-term energy storage and for applications that necessitate the transportation of energy across seasons or continents. This is since hydrogen can be stored for prolonged periods without experiencing any substantial energy loss [19].	Lithium-ion batteries are highly proficient in offering energy storage solutions for short to medium durations. They are particularly effective in handling variations in renewable energy production and serving as a reliable backup power source during power outages [20].
Energy Density	In comparison to lithium batteries, it is common for this type of battery to possess a higher energy density. This implies that it can store a greater amount of energy per unit mass or volume. As a	While hydrogen fuel cells usually have higher energy density than lithium batteries, recent advancements have greatly boosted the energy densities of lithium batteries. This makes them more appropriate for applications that require

	result, it proves to be beneficial for applications that demand prolonged energy storage or high-power output [21].	compact and lightweight energy storage solutions [22].
Charging and Refuelling	Hydrogen fuel cell vehicles can be refuelled similarly to conventional gasoline vehicles, requiring just a few minutes. Nevertheless, it is important to note that the availability of hydrogen refuelling infrastructure is still restricted in numerous regions [23].	Typically, charging a lithium battery takes more time than refuelling a hydrogen fuel cell vehicle, especially with high-capacity batteries. Nevertheless, the widespread availability of electric charging stations offers greater convenience for numerous users [24].
Environmental Impact	Charging a lithium battery usually requires more time compared to refuelling a hydrogen fuel cell vehicle, particularly when dealing with high-capacity batteries. However, the extensive presence of electric charging stations provides enhanced convenience for a multitude of users [25].	Electric vehicles are commonly recognized as eco-friendly during their operation due to their emission-free nature. Nonetheless, it is crucial to note that the extraction and processing of lithium, as well as the appropriate disposal of batteries at the end of their life cycle, can lead to environmental impacts if not effectively managed [26].
Decarbonization of Hard-to-Electrify Sectors	Green hydrogen is especially important for decarbonizing divisions that are challenging to zap specifically, such as overwhelming industry, flying, and long-haul shipping [27].	Lithium-ion batteries are well-suited for energizing light and a few medium-duty vehicles, as well as giving network soundness [28].
Cost	As of now, hydrogen fuel cell innovation tends to be more costly compared to lithium batteries, to a great extent due to the fetching of creating and putting away hydrogen and the framework required for its dispersion [29].	Costs have been diminishing relentlessly over a long time due to progressions in innovation, economies of scale, and advancements in fabricating forms, making lithium batteries more cost-effective for numerous applications [30].
Applications	Regularly utilized in applications where long-range, quick refuelling, and high-power yield are required, such as in fuel cell vehicles, reinforcement control frameworks, and network vitality capacity [23].	Broadly utilized in convenient gadgets, electric vehicles, renewable vitality capacity frameworks (such as sun-powered and wind), and framework stabilization due to their flexibility and generally taking a toll [25].

V. Challenges in Hydrogen Fuel Cell and Lithium Batteries:

- **Lithium-ion battery:** Lithium-ion batteries have ended up omnipresent in cutting-edge innovation due to their tall vitality thickness, rechargeability, and moderately moo upkeep compared to other battery sorts. In any case, they moreover come with a few challenges[31]:

1. **Safety Concern:** Lithium-ion batteries can be inclined to overheat and, in a few cases, catch fire or detonate. Typically, frequently due to fabricating absconds, harm, or dishonorable utilization. Guaranteeing appropriate taking care of, capacity, and fabricating forms are basic to relieve security dangers[32].

2. **Limited Lifespan:** Lithium-ion batteries corrupt over time, driving to diminish in capacity and in general execution. This corruption is quickened by components such as tall temperatures, profound releases, and visit charging cycles. Overseeing battery utilization and executing compelling battery administration frameworks can help drag out their life expectancy [33].
3. **Resource Constraints:** The generation of lithium-ion batteries depends on the accessibility of certain uncommon soil metals and minerals like lithium, cobalt, and nickel. This reliance can lead to supply chain imperatives and cost changes, particularly as requests for electric vehicles and renewable vitality capacity arrangements proceed to rise. Inquiring about into elective materials and reusing strategies is continuous to address these concerns [34].
4. **Environmental Impact:** The extraction and handling of lithium and other crude materials for battery generation can have natural results, including living space annihilation, water contamination, and carbon outflows. Furthermore, inappropriate transfer of batteries can lead to harmful chemical spillage into soil and water. Creating maintainable generation strategies and expanding battery reusing endeavours are basic to relieve these natural impacts [35].
5. **Weight and Size:** Whereas lithium-ion batteries offer tall vitality thickness compared to other sorts of batteries, they still have restrictions in terms of weight and measure, particularly for applications where space and weight are basic components, such as in aviation or wearable gadgets. Investigate into modern battery chemistries and advance points to address these impediments [28].
6. **Charging Infrastructure:** The broad selection of electric vehicles (EVs) and renewable vitality capacity frameworks requires a strong charging foundation. The accessibility of fast-charging stations and lattice capacity to back high-energy requests is fundamental for the standard selection of electric vehicles and renewable vitality capacity arrangements [36].

Tending to these challenges requires collaboration among analysts, producers, policymakers, and shoppers to create inventive arrangements that improve the execution, security, and supportability of lithium-ion batteries.
The fabricating and transfer of lithium-ion batteries have continuously been the subjects of political and natural concerns, with their significant related contamination and non-renewable vitality sources of lithium and other key assets remaining profoundly related. With dangerously developing numbers of electric cars (and expanding battery estimates) in couple with the fast transfer of lithium-ion batteries in smartphones and other buyer hardware, vitality squander and dependence on non-renewable assets are getting more noteworthy. It is expected that in 2040, 58% of all cars sold around the world will be electric cars, and the full sum of squander produced can be as much as 8 million tons. Much later investigation on lithium-ion batteries, subsequently, has cantered on how to reuse[37] them, with the point of diminishing contamination and facilitating weight on mineral saves. Nowadays, as it were around 5% of lithium-ion batteries are reused all-inclusive because of impediments, such as fluctuating monetary values of battery materials, the need for mechanical merging in battery plans and materials (and related reusing labour costs) as well as inside reusing offices, need of monetization of numerous reusing benefits (counting fabric security, security, and natural benefits) and nonappearance of reusing controls over much of the world.

- **Hydrogen Fuel Cell:** Although the costs of hydrogen fuel cells are critical largely owing to the utilization of platinum, the most prominent challenge is the trouble in putting away (and transporting) H2. Without a doubt, the victory of H2 as a customer fuel specifically depends on finding vigorous H2 capacity materials and creating a refined, secure framework for its transportation [38].

  Hydrogen fuel cells offer a promising elective to conventional inside combustion motors and batteries for controlling vehicles and giving power. Be that as it may, a few challenges prevent their far-reaching selection[10]:

1. **Hydrogen Production:** Most of the hydrogen created nowadays comes from fossil fuels through forms like steam methane transforming, which radiates nursery gasses. Creating hydrogen through renewable strategies like the electrolysis of water is cleaner but as of now more costly and energy-intensive. Scaling up renewable hydrogen generation whereas diminishing costs is fundamental for the natural benefits of hydrogen fuel cells to be realized [39].
2. **Storage and Distribution:** Hydrogen includes a moo vitality thickness by volume, making it challenging to store and transport effectively. Compressing hydrogen gas or liquefying it requires vitality and a specialized framework. Creating cost-effective and secure capacity and dissemination strategies, such as progressed tanks or pipelines, is pivotal for setting up a hydrogen economy [40].
3. **Cost:** Hydrogen fuel cell frameworks are right now more costly than inside combustion motors or battery-electric frameworks. Usually somewhat due to the tall taking a toll on fuel cell innovation and the moderate moo volume of generation compared to other options. Accomplishing economies of scale, progressing fabricating forms, and decreasing the utilization of costly materials like platinum in fuel cells is fundamental to making hydrogen fuel cells more competitive [13].
4. **Infrastructure:** Building a hydrogen-fuelled framework could be a critical boundary to appropriation. Not at all like gasoline or electric charging stations, are hydrogen fuelling stations rare and costly to introduce? Growing the organization of hydrogen refuelling stations requires significant venture and coordination between governments, private companies, and other partners [41].
5. **Durability and Reliability:** Fuel cell strength and unwavering quality are basic for vehicle execution and client acknowledgment. Fuel cells can corrupt over time due to variables like catalyst harming, film debasement, or hydrogen debasement. Progressing the life span and vigor of fuel cell frameworks through superior materials and plan is basic for their commercial reasonability [41].
6. **Safety Concerns:** Hydrogen is exceedingly combustible and can display security dangers if not dealt with legitimately. Guaranteeing the secure generation, capacity, transportation, and utilization of hydrogen is vital to building open belief in fuel cell innovation. Actualizing thorough security guidelines, preparation, and directions can moderate these dangers [39].
7. **Efficiency:** Whereas hydrogen fuel cells can be profoundly productive in changing hydrogen into power, the by and large productivity of the hydrogen generation, conveyance, and transformation handle can be lower compared to battery-electric vehicles. Optimizing each step of the hydrogen supply chain to move forward productivity is basic for lessening vitality utilization and nursery gas outflows.[42]

Tending to these challenges requires concerted endeavours from governments, industry partners, and researchers to overcome mechanical, financial, and administrative obstructions to hydrogen fuel cell selection. Proceeded development and venture in inquiry about and improvement are basic for opening up the complete potential of hydrogen as a clean vitality carrier.

VI. Comparison According to the Efficiency:

No energy source is 100% efficient. Some energy is lost when converted into other forms of energy. Energy can be lost in many forms such as heat, light, sound, or loss of magnetism. The aim is to reduce the amount of energy lost to improve efficiency. The EV powertrain uses a battery or fuel cell that is significantly more energy efficient than a gasoline engine, which can lose up to 80% of its energy through engine heat, evaporation, oil extraction, oil filtration, and operation [43]. However, batteries and fuel cells are not immune. Energy loss can occur during storage, charging, and discharging. Batteries have significantly lower energy losses than fuel cells. Batteries can reuse 80 to 90% of the stored chemical energy. Part of the energy lost as heat can be reused for other purposes, for example, to heat the cabin of an electric vehicle or even to heat meals for passengers on an airplane. Reusing energy lost as heat is called cogeneration. Electric vehicle manufacturers effectively use this method to reduce battery drain. By heating the cabin with energy lost to heat, they can avoid discharging the battery. Meanwhile, fuel cells typically convert 40-60% of their energy to generate electrical power [44][45]. Theoretically, the use of cogeneration from waste heat could improve the energy efficiency of fuel cells by up to 85%. In cold weather, fuel cells can operate almost as efficiently as batteries. Electric vehicle batteries use up to 40% of electrical energy for heating.

VII. Impact on Health:

The shift from internal combustion engines (ICEs) to hydrogen fuel cells (HFCs) and lithium batteries (LIBs) is not only a move towards environmental sustainability but also a crucial step in mitigating adverse health effects caused by vehicular emissions. Fossil fuel-powered vehicles emit a mix of pollutants, including carbon monoxide (CO), nitrogen oxides (NOx), sulfur dioxide (SO2), and particulate matter (PM2.5). These pollutants are known to contribute to respiratory illnesses, cardiovascular diseases, and even cancer [46].

Health Benefits of Hydrogen Fuel Cells and Lithium Batteries:

1. **Reduction in Airborne Pollutants:** Both HFCs and LIBs eliminate tailpipe emissions, significantly reducing urban air pollution. This reduction can lower incidences of asthma, chronic bronchitis, and other respiratory disorders [47].
2. **Minimized Noise Pollution:** Electric vehicles powered by HFCs or LIBs produce less noise compared to conventional ICE vehicles. Lower noise levels contribute to reduced stress and improved mental health in urban settings [48].
3. **Improved Indoor and Outdoor Air Quality:** Widespread adoption of these technologies will lead to better air quality, particularly in densely populated cities. This improvement has a direct positive impact on vulnerable populations, including children and the elderly [49].

Potential Challenges:

1. **Battery Production and Recycling:** The extraction of materials like lithium and cobalt can lead to localized environmental degradation, impacting nearby communities' health through contaminated water and soil [50].
2. **Hydrogen Safety Concerns:** Although HFCs are environmentally friendly, the safe production, storage, and transportation of hydrogen are critical. Hydrogen leaks, if not managed correctly, pose safety risks, potentially causing injuries in the event of an accident [51].

Future Research Directions: To maximize health benefits, additional research is required to:

- Develop sustainable battery recycling methods to minimize environmental and health impacts [51].
- Advance hydrogen storage technologies to improve safety and reliability [52].
- Study the long-term health benefits of reduced urban air pollution due to widespread adoption of HFC and LIB technologies [53].

Conclusion:

In conclusion, green hydrogen and lithium-ion capacity are complementary advances that can coexist and bolster the move to a low-carbon vitality future. Their selection will depend on the needs and characteristics of diverse segments and applications, and both have vital parts to play in lessening nursery gas outflows and progressing clean vitality arrangements. Instead of one overwhelming the other, their integration and collaboration are likely to be key drivers in accomplishing supportability objectives. Both advances have their qualities and confinements, and the choice between them depends on the necessities of the application, counting components such as vitality thickness, charging/refuelling framework, natural contemplations, and fetching.

References:

[1] L. Chapman, "Transport and climate change: a review," *J. Transp. Geogr.*, vol. 15, no. 5, pp. 354–367, 2007, doi: 10.1016/j.jtrangeo.2006.11.008.

[2] A. M. Al-Ghaili, H. Kasim, H. Aris, and N. M. Al-Hada, "Can electric vehicles be an alternative for traditional fossil-fuel cars with the help of renewable energy sources towards energy sustainability achievement?," *Energy Informatics*, vol. 5, no. 4, pp. 1–24, 2022, doi: 10.1186/s42162-022-00234-3.

[3] E. R. Sadik-Zada, A. Gatto, and M. Scharfenstein, "Sustainable management of lithium and green hydrogen and long-run perspectives of electromobility," *Technol. Forecast. Soc. Change*, vol. 186, no. PA, p. 121992, 2023, doi: 10.1016/j.techfore.2022.121992.

[4] S. S. G. Acharige, M. E. Haque, M. T. Arif, N. Hosseinzadeh, K. N. Hasan, and A. M. T. Oo, "Review of Electric Vehicle Charging Technologies, Standards, Architectures, and Converter Configurations," *IEEE Access*, vol. 11, no. February, pp. 41218–41255, 2023, doi: 10.1109/ACCESS.2023.3267164.

[5] F. Rahim Malik, H. B. Yuan, J. C. Moran, and N. Tippayawong, "Overview of hydrogen production technologies for fuel cell utilization," *Eng. Sci. Technol. an Int. J.*, vol. 43, p. 101452, 2023, doi: 10.1016/j.jestch.2023.101452.

[6] J. Balakrishnan, "Fuel Cell Technology in Pakistan," p. 2005, 2005.

[7] K. E. Okedu, D. Pawar, R. Uhunmwangho, R. A. John, and P. Madifie, "Hydrogen production in hybrid renewable energy system and power factor improvement," *2016 3rd Int. Conf. Electr. Energy Syst. ICEES 2016*, pp. 201–206, 2016, doi: 10.1109/ICEES.2016.7510641.

[8] O. Onalaja, Y. Abdullahi, Taofeek, and Lawal Ayodeji, "Review of Hydrogen Fuel Cell Technology and Its Application," 2024.

[9] M. Elmahallawy, T. Elfouly, A. Alouani, and A. M. Massoud, "A Comprehensive Review of Lithium-Ion Batteries Modeling, and State of Health and Remaining Useful Lifetime Prediction," *IEEE Access*, vol. 10, no. October, pp. 119040–119070, 2022, doi: 10.1109/ACCESS.2022.3221137.

[10] G. J. Offer, D. Howey, M. Contestabile, R. Clague, and N. P. Brandon, "Comparative analysis of battery electric, hydrogen fuel cell and hybrid vehicles in a future sustainable road transport system," *Energy Policy*, vol. 38, no. 1, pp. 24–29, 2010, doi: 10.1016/j.enpol.2009.08.040.

[11] I. Staffell *et al.*, "The role and status of hydrogen and fuel cells across the global energy system," *Osf*, no. c, 2018.

[12] H. Ali, H. A. Khan, and M. G. Pecht, "Circular economy of Li Batteries: Technologies and trends," *J. Energy Storage*, vol. 40, no. May, p. 102690, 2021, doi: 10.1016/j.est.2021.102690.

[13] Q. Hassan, I. D. J. Azzawi, A. Z. Sameen, and H. M. Salman, "Hydrogen Fuel Cell Vehicles: Opportunities and Challenges," *Sustain.*, vol. 15, no. 15, 2023, doi: 10.3390/su151511501.

[14] N. Rane, S. Choudhary, and J. Rane, "Enhancing lithium-ion battery performance with emerging electrolyte materials for sustainable energy storage solutions: a comprehensive review and prospects," *SSRN Electron. J.*, no. January, 2023, doi: 10.2139/ssrn.4643648.

[15] D. Li *et al.*, "Energy management of solid oxide fuel cell/lithium battery hybrid system," *CSEE J. Power Energy Syst.*, pp. 1–14, 2022, doi: 10.17775/CSEEJPES.2021.00640.

[16] Y. Song *et al.*, "Utilization of Energy Storage and Hydrogen in Power and Energy Systems: Viewpoints from Five Aspects," *CSEE J. Power Energy Syst.*, vol. 9, no. 1, pp. 1–7, 2023, doi: 10.17775/CSEEJPES.2022.08320.

[17] L. I. M. Asri, W. N. S. F. W. Ariffin, A. S. M. Zain, J. Nordin, and N. S. Saad, "Comparative Study of Energy Storage Systems (ESSs)," *J. Phys. Conf. Ser.*, vol. 1962, no. 1, 2021, doi: 10.1088/1742-6596/1962/1/012035.

[18] T. Chen *et al.*, "Applications of Lithium-Ion Batteries in Grid-Scale Energy Storage Systems," *Trans. Tianjin Univ.*, vol. 26, no. 3, pp. 208–217, 2020, doi: 10.1007/s12209-020-00236-w.

[19] I. Marouani *et al.*, "Integration of Renewable-Energy-Based Green Hydrogen into the Energy Future," *Processes*, vol. 11, no. 9, 2023, doi: 10.3390/pr11092685.

[20] A. Aghmadi and O. A. Mohammed, "Energy Storage Systems: Technologies and High-Power Applications," *Batteries*, vol. 10, no. 4, 2024, doi: 10.3390/batteries10040141.
[21] Y. Chen *et al.*, "A review of lithium-ion battery safety concerns: The issues, strategies, and testing standards," *J. Energy Chem.*, vol. 59, pp. 83–99, 2021, doi: 10.1016/j.jechem.2020.10.017.
[22] M. H. Hossain, M. A. Chowdhury, N. Hossain, M. A. Islam, and M. H. Mobarak, "Advances of lithium-ion batteries anode materials—A review," *Chem. Eng. J. Adv.*, vol. 16, no. October, p. 100569, 2023, doi: 10.1016/j.ceja.2023.100569.
[23] Y. Manoharan, S. E. Hosseini, B. Butler, and H. Alzhahrani, "App9112296.Pdf," 2019.
[24] M. S. Mastoi *et al.*, "An in-depth analysis of electric vehicle charging station infrastructure, policy implications, and future trends," *Energy Reports*, vol. 8, pp. 11504–11529, 2022, doi: 10.1016/j.egyr.2022.09.011.
[25] M. Kumar, K. P. Panda, R. T. Naayagi, R. Thakur, and G. Panda, "Comprehensive Review of Electric Vehicle Technology and Its Impacts: Detailed Investigation of Charging Infrastructure, Power Management, and Control Techniques," *Appl. Sci.*, vol. 13, no. 15, 2023, doi: 10.3390/app13158919.
[26] F. Alanazi, "Electric Vehicles: Benefits, Challenges, and Potential Solutions for Widespread Adaptation," *Appl. Sci.*, vol. 13, no. 10, 2023, doi: 10.3390/app13106016.
[27] M. Jayachandran *et al.*, "Challenges and Opportunities in Green Hydrogen Adoption for Decarbonizing Hard-to-Abate Industries: A Comprehensive Review," *IEEE Access*, vol. 12, pp. 23363–23388, 2024, doi: 10.1109/ACCESS.2024.3363869.
[28] S. S. Rangarajan *et al.*, "Lithium-Ion Batteries—The Crux of Electric Vehicles with Opportunities and Challenges," *Clean Technol.*, vol. 4, no. 4, pp. 908–930, 2022, doi: 10.3390/cleantechnol4040056.
[29] D. De Wolf and Y. Smeers, "Comparison of Battery Electric Vehicles and Fuel Cell Vehicles," *World Electr. Veh. J.*, vol. 14, no. 9, pp. 1–13, 2023, doi: 10.3390/wevj14090262.
[30] M. Khan, "Innovations in Battery Technology: Enabling the Revolution in Electric Vehicles and Energy Storage," *Br. J. Multidiscip. Adv. Stud.*, vol. 5, no. 1, pp. 23–41, 2024, doi: 10.37745/bjmas.2022.0414.
[31] X. Zhou, N. Qi, L. Cheng, L. Tian, Y. Wan, and F. You, "Research on Lithium-ion Battery Safety Risk Assessment Based on Measured Information," no. 2018, pp. 1–6.
[32] J. Zhang, L. Zhang, F. Sun, and Z. Wang, "An Overview on Thermal Safety Issues of Lithium-ion Batteries for Electric Vehicle Application," *IEEE Access*, vol. 6, pp. 23848–23863, 2018, doi: 10.1109/ACCESS.2018.2824838.
[33] M. Kopp, A. Fill, M. Ströbel, and K. P. Birke, "A Novel Long Short-Term Memory Approach for Online State-of-Health Identification in Lithium-Ion Battery Cells," *Batteries*, vol. 10, no. 3, 2024, doi: 10.3390/batteries10030077.
[34] P. Barman, L. Dutta, and B. Azzopardi, "Electric Vehicle Battery Supply Chain and Critical Materials: A Brief Survey of State of the Art," *Energies*, vol. 16, no. 8, 2023, doi: 10.3390/en16083369.
[35] W. Mrozik, M. A. Rajaeifar, O. Heidrich, and P. Christensen, "Environmental impacts, pollution sources and pathways of spent lithium-ion batteries," *Energy Environ. Sci.*, vol. 14, no. 12, pp. 6099–6121, 2021, doi: 10.1039/d1ee00691f.
[36] M. Yao, D. Da, X. Lu, and Y. Wang, "A Review of Capacity Allocation and Control Strategies for Electric Vehicle Charging Stations with Integrated Photovoltaic and Energy Storage Systems," *World Electr. Veh. J.*, vol. 15, no. 3, 2024, doi: 10.3390/wevj15030101.
[37] M. Pagliaro and F. Meneguzzo, "Lithium battery reusing and recycling: A circular economy insight," *Heliyon*, vol. 5, no. 6, p. e01866, 2019, doi: 10.1016/j.heliyon.2019.e01866.
[38] O. Fakhreddine, Y. Gharbia, J. F. Derakhshandeh, and A. M. Amer, "Challenges and Solutions of Hydrogen Fuel Cells in Transportation Systems: A Review and Prospects," *World Electr. Veh. J.*, vol. 14, no. 6, 2023, doi:

10.3390/wevj14060156.
[39] S. G. Nnabuife, C. K. Darko, P. C. Obiako, B. Kuang, X. Sun, and K. Jenkins, "A Comparative Analysis of Different Hydrogen Production Methods and Their Environmental Impact," *Clean Technol.*, vol. 5, no. 4, pp. 1344–1380, 2023, doi: 10.3390/cleantechnol5040067.
[40] M. Nachtane *et al.*, "An Overview of the Recent Advances in Composite Materials and Artificial Intelligence for Hydrogen Storage Vessels Design," *J. Compos. Sci.*, vol. 7, no. 3, 2023, doi: 10.3390/jcs7030119.
[41] S. Campíñez-Romero, A. Colmenar-Santos, C. Pérez-Molina, and F. Mur-Pérez, "A hydrogen refuelling stations infrastructure deployment for cities supported on fuel cell taxi roll-out," *Energy*, vol. 148, no. 2018, pp. 1018–1031, 2018, doi: 10.1016/j.energy.2018.02.009.
[42] IRENA, *Hydrogen: a Renewable Energy Perspective*, no. September. 2019.
[43] J. A. Sanguesa, V. Torres-Sanz, P. Garrido, F. J. Martinez, and J. M. Marquez-Barja, "Kampman," *Smart Cities*, vol. 4, no. 1, pp. 372–404, 2021.
[44] S. Rashidi, N. Karimi, B. Sunden, K. C. Kim, A. G. Olabi, and O. Mahian, "Progress and challenges on the thermal management of electrochemical energy conversion and storage technologies: Fuel cells, electrolysers, and supercapacitors," *Prog. Energy Combust. Sci.*, vol. 88, no. December 2020, p. 100966, 2022, doi: 10.1016/j.pecs.2021.100966.
[45] A. Ieee, E. Public, P. Committee, and P. Statement, "IEEE European Public Policy Committee The Role of Green Hydrogen in a Low Carbon Future IEEE European Public Policy Committee," no. August, pp. 1–9, 2022.
[46] WHO, "Air Pollution and Child Health: Prescribing Clean Air," World Health Organization, 2018.
[47] J. Lelieveld, K. Klingmüller, A. Pozzer, et al., "Effects of fossil fuel combustion on human health," Proc. Natl. Acad. Sci., vol. 116, no. 15, pp. 7192–7200, 2019.
[48] EEA, "Noise in Europe 2020," European Environment Agency, 2020.
[49] H. Landrigan et al., "Pollution and Global Health", Lancet Commission on Pollution and Health, 2017.
[50] A. Manu and P. E. Ayoko, "Environmental and health impacts of cobalt extraction," J. Sustain. Min., vol. 17, pp. 46–52, 2018.
[51] D. Friedl et al., "Hydrogen safety considerations in mobility," Int. J. Hydrogen Energy, vol. 46, no. 60, pp. 31024–31045, 2021.
[52] M. Pagliaro and F. Meneguzzo, "Lithium battery reusing and recycling: A circular economy insight," Heliyon, vol. 5, no. 6, p. e01866, 2019.
[53] M. Nachtane et al., "An Overview of the Recent Advances in Composite Materials and Artificial Intelligence for Hydrogen Storage Vessels Design," J. Compos. Sci., vol. 7, no. 3, 2023.
[54] E. S. Bernard et al., "Urban Air Quality Improvements and Public Health Benefits from Electric Vehicles," Environ. Res., vol. 204, no. 3, p. 112028, 2022.