Application of lithium batteries, hydrogen fuel cells and solar energy in transportation field

Hongda Li

LUT School of Energy Systems, LUT University, 15210 Lahti, Finland

Hongda.Li@student.lut.fi

Abstract. The transportation sector has a significant impact on worldwide energy use and carbon emissions. With the growing concern about climate change and the need for sustainable development, the transition of the transport system to clean energy has become a top priority. Because of high energy density and long cycle life, lithium batteries have made significant progress in the application of electric cars. Hydrogen fuel cells offer a viable alternative because they provide efficient and emission-free propulsion for various types of vehicles. The integration of solar energy into the transportation system provides opportunities for renewable energy generation. The energy transformation of transport systems has great potential. Continued advances in battery technology, widespread adoption of hydrogen infrastructure, and innovations in solar integration will play a key role in helping to build a more efficient and resilient transportation network. This research explores three key technologies that promise to enable the clean energy transition in transportation, including lithium batteries, hydrogen fuel cells and solar energy. The implications of the transport sector's transition to these sustainable energy technologies are profound. It will not only reduce greenhouse gas emissions, but also enhance energy security, diversify resources, and support economic growth by creating new jobs. In addition, the shift to clean transportation will improve air quality, mitigate health risks and promote sustainable urban development.

Keywords: transportation, lithium batteries, hydrogen fuel cells, solar energy.

1. Introduction

The transportation sector relies on traditional fossil fuels. However, fuels such as gasoline and diesel release carbon dioxide (CO_2), nitrogen oxides, and other pollutants into the atmosphere when burned. The CO_2 emissions per capita in 2020 reached 40.8 t CO_2/capita. In 2022, CO_2 emissions from the global transport sector grew by more than 250 million tonnes to nearly 8 billion tonnes of CO_2, a 3% increase over 2021. For global warming, the transport sector contributes roughly 24% of the world's CO_2 emissions [1]. In addition, as global car ownership and use continues to increase, it is likely to further increase carbon emissions from the transport sector if appropriate measures are not taken. The heavy reliance on fossil fuels raises concerns about environmental sustainability, energy security, and climate change mitigation. To address these challenges, the need for a comprehensive energy transition in the transport sector is becoming increasingly apparent.

At present, the internal combustion engine vehicles represented by gasoline and diesel are still dominant in the current transportation field, but this kind of internal combustion engine vehicles will

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cause a lot of harm. First of all, internal combustion engine vehicles rely heavily on non-renewable fossil fuels such as oil, which will lead to further intensification of carbon emissions, which will have an irreversible impact on climate change and environmental change. Secondly, pollutants such as volatile organic compounds emitted by internal combustion engine vehicles will cause air pollution and adversely affect human health [2, 3]. Therefore, the transportation sector needs to urgently complete the transition from traditional energy to new energy. Reliance on fossil fuels, especially gasoline, and diesel, has led to rising levels of carbon emissions and air pollution. This has adverse effects on human health, ecosystem stability, and overall climate patterns. The transition to new energy modes of transport is important to mitigate these adverse effects and protect the environment.

In recent years, there has been an increase in the quest for alternative energy sources and the creation of new technologies to power the transportation sector. These alternatives include hydrogen fuel cells and other renewable energy solutions. Transitioning to these cleaner and more sustainable options compared to traditional fossil fuels offers the opportunity to reduce emissions, minimize dependence on fossil fuels, and create a more resilient and diversified energy system. At the same time, considering the shortcomings and problems of internal combustion engine vehicles, the adoption of electric vehicles as a solution to reduce greenhouse gas emissions is conducive to a significant reduction in carbon emissions and can help decarbonize the transport sector [4]. Advances in battery technology and the improvement of charging facilities have made electric vehicles a more practical choice for consumers. Electric vehicles continued to gain momentum in 2022, with more than 100,000 units sold globally, accounting for 14% of all vehicle sales. More and more people are using electric cars instead of internal combustion engines.

To sum up, the current heavy reliance on traditional energy sources in the transportation sector has caused serious environmental pollution and health risks. To lessen air pollution and combat climate change, the energy transition in the transport sector is a key step towards achieving the sustainable development goals. This research will introduce the current development status of energy transformation in the transport sector from the three specific areas of lithium batteries, hydrogen fuel cells, and solar energy utilization, understand the importance of these three areas in the transport field, and analyze their development advantages and existing limitations, which can pave the way for the establishment of a more sustainable, more efficient and more environmentally friendly transport system. It also provides thoughts and suggestions for further promoting the energy transition in the transportation sector and the popularization of electric vehicles.

2. Lithium battery

The lithium battery is a rechargeable battery that stores and releases electrical energy by inserting and removing lithium ions between the positive and negative electrodes. Therefore, lithium batteries usually consist of a positive electrode (such as lithium cobalt oxide), a carbon-based negative electrode (such as graphite), and electrolyte for conducting ions and a separator. Lithium batteries operate by facilitating the movement of lithium ions between the positive and negative electrodes, enabling the process of charging and discharging. During this process of lithium ions being released from the positive electrode and traversing the electrolyte towards the negative electrode, the battery enters a state of discharge. In this state, it releases electricity to power the external circuit. When the external power supply generates a current that prompts the migration of lithium ions back to the positive electrode for re-embedding, the battery enters a state of charge [5]. In general, lithium batteries have made significant progress in energy density, output power, cycle life, charging rate and monthly self-discharge rate in recent years. These improvements provide a solid foundation for technological advances in transportation such as electric vehicles. Table 1 shows specific values for these properties.

Table 1. Performances of different types of lithium batteries [6, https://batteryuniversity.com/article/bu-205-types-of-lithium-ion].

Name	Specific energy (Wh/kg)	Voltages (V)	Cycle life (times)	Charging rate (C)	Thermal runaway (℃)
Li-polymer	100-130	3.6	300-500	1	150
$LiFePO_4$-graphite	90-120	3.2	>2000	1	270
$LiCoO_2$-graphite	140-200	3.6	500-1000	0.7-1	150

Lithium batteries have developed rapidly in the past few years and are gradually becoming the main energy storage technology. In the realm of electric vehicles, the progress of lithium batteries as an energy storage technology can be primarily observed in two key aspects. Firstly, with the development of new materials, the optimization of electrode structure and the improvement of manufacturing process and other aspects of innovation, the level of lithium battery technology continues to improve. As a carrier of energy storage for electric vehicles, the energy density and capacity density of lithium batteries continue to increase, making the driving range of electric vehicles has also been greatly improved. The energy density of the mainstream lithium iron phosphate battery is below 200 Wh/kg, and the energy density of the ternary lithium battery is between 200-300 Wh/kg. California company Amprius announced that it has produced the first ultra-high energy density lithium battery, which has a battery density of 450 Wh/kg. Secondly, the application of new electrolyte materials and flame retardants, the optimization of thermal management systems, and the advancement of safety control technology have effectively reduced the risk of overheating, explosion, and other safety events of lithium batteries, and the safety of lithium batteries has been greatly improved. In addition, the market size of lithium batteries is also expanding. In 2018, the global lithium-ion battery industry scale exceeded 40 billion US dollars for the first time, reaching 41.2 billion US dollars, an increase of 18% year-on-year. In terms of capacity, the global lithium-ion battery market reached 200 GWh, an increase of 25% year-on-year.

Lithium batteries have several advantages, making them one of the most popular energy solutions in modern electronic devices and vehicles [7]. The following is a specific explanation of its advantages. For high energy density, lithium batteries possess a significant energy density, which means that lithium batteries can store more energy and can provide a longer driving range, thus ensuring that electric vehicles can meet the needs of users. For high power output, lithium batteries can release electricity quickly and have high power output capacity. This ensures that lithium batteries can achieve high power requirements such as acceleration or climbing in electric vehicles. For long cycle life, by controlling the depth of charge and discharge, temperature, charge and discharge rate, and correct storage conditions, the lithium battery can achieve a long cycle life, so as to maximize the reliability and durability of the lithium battery.

At the same time as the rapid development of lithium batteries, there are still limitations to be solved as an energy storage device for storing electric energy. First, lithium-ion batteries have limited cycle life and capacity decay problems. With the increase in the number of cycles, the capacity of lithium-ion batteries is gradually reduced. And to a certain extent, it will affect its service life and performance stability. Secondly, some electrolyte components may decompose under high voltage and high-temperature conditions, resulting in gases and sediments. These side reactions can lead to an increase in pressure inside the battery, which can cause a fire or explosion. At the same time, the components and reaction products in the electrolyte can react with lithium metal through an electrochemical reaction to form an unstable solid interface. This interface instability will lead to battery capacity attenuation and cycle performance degradation [8].

3. Hydrogen fuel cells

A hydrogen fuel cell is an apparatus that generates electricity through the chemical reaction between hydrogen and oxygen. They belong to a class of renewable energy technologies that are

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environmentally friendly, efficient, and zero-emission. Hydrogen fuel cells work on the basis of an electrochemical reaction between hydrogen and oxygen on both sides of an electrolyte membrane (usually a polymer electrolyte membrane). At the negative end, hydrogen molecules (H_2) are broken down by a catalyst into protons (H^+) and electrons (e^-). Protons travel through the electrolyte membrane, while electrons flow along the external circuit, creating an electric current. At the positive extreme, oxygen molecules (O_2) react with protons and electrons to form water (H_2O) as a by-product.

The reaction releases a large amount of energy and converts it into electricity. Hydrogen fuel cells include many key components, such as the anode, cathode, electrical guide plate, and hydrogen supply system. Hydrogen fuel cells have a wide range of potential applications in the fields of transportation, mobile devices, and distributed energy. Hydrogen fuel cells are regarded as a crucial component of forthcoming clean energy systems owing to their high efficiency, minimal emissions, and ability to harness renewable energy [9]. The development of hydrogen fuel cells in the field of transportation has been concerned and is considered one of the potential solutions for future sustainable transportation systems. By the end of 2022, the number of fuel cell electric vehicles (FCEVs) is 72100. At the same time, the number of the hydrogen refuelling station (HRS) is 1020 [10].

There is increasing collaboration between car manufacturers, energy companies, and technology companies around the world, with key alliances and collaborative projects such as the "Hydrogen Council" and "H_2 Mobility" being established to promote the commercial application of hydrogen fuel cells and jointly promote the development and progress of hydrogen fuel cell technology. Therefore, with the improvement of technology, policy support and the increase of market demand, hydrogen fuel cells are expected to gradually become one of the important areas of energy transformation in the field of transportation.

The reason why hydrogen fuel cells can attract the attention of all walks of life is closely related to their own advantages. First, compared to conventional fuel cars, hydrogen fuel cells use hydrogen to react with oxygen to produce electricity, and only water vapor is produced as exhaust emissions. Therefore, hydrogen fuel cells achieve zero emissions, which is conducive to being a solution for energy transformation and promoting sustainable development of the environment. Secondly, hydrogen as a fuel has a high energy density. Hydrogen can be stored at a higher energy density than batteries and converted into electricity to power vehicles. This means that hydrogen fuel cell vehicles can provide a longer driving range. At the same time, the refuelling time of hydrogen fuel cell vehicles is faster than the charging time of electric vehicles. The refuelling process is similar to traditional car refuelling and can be completed in just a few minutes. This fast fuelling makes hydrogen fuel cell vehicles competitive for long distances and commercial operations.

While hydrogen fuel cell is very competitive in the market, many defects cannot be ignored. (1) High-temperature polymer electrolyte membrane fuel cells necessitate operation at elevated temperatures. This creates additional challenges for system design and engineering, with higher requirements for material selection, thermal management, and system control. (2) Under low-temperature conditions, the hot expansion and cold contraction generated by frequent starting and stopping the conversion of automobiles can easily cause battery damage; And the aging and degradation of the proton exchange membrane, the core material of the stack, leads to a gradual decrease in fuel cell performance, which affects the fuel battery life [11]. (3) Hydrogen is highly combustible and poses safety risks during storage and distribution. Leakage of hydrogen can cause an explosion or fire, so strict safety measures must be taken to prevent accidents. At the same time, hydrogen is highly combustible and poses safety risks during storage and distribution. Leakage of hydrogen can cause an explosion or fire, so strict safety measures must be taken to prevent accidents [12].

4. Utilization of solar energy

In the realm of transportation, the integration of solar energy has progressively emerged as a significant trend in the energy transition. The development of solar energy in the field of transportation is mainly reflected in different aspects. (1) With the popularity of electric vehicles, the demand for solar charging facilities has also increased. Many cities have begun to install solar charging piles, a type of charging facility that collects solar energy through solar panels and converts it into electricity that can be stored for electric vehicles to charge. (2) Solar car refers to an electric vehicle with solar panels. These panels are mounted on the roof of the car and convert solar energy into electricity. Solar cars can use solar energy to charge, extend driving range, reduce dependence on traditional power grids and reduce environmental pollution. At present, the technology and performance of solar vehicles are constantly improving, making them an important choice for energy transformation in the transportation sector. (3) Solar energy can also be used to supply energy to other transportation infrastructure. For example, solar panels can be installed in locations such as roads, Bridges and tunnels to convert solar energy into electricity for lighting, signal lights and other devices, thus enabling energy recycling.

According to the forecast, by 2030, the world will have 5.5 million public fast charging piles and 10 million public slow charging piles, including solar charging piles and other renewable energy-driven charging facilities. The electricity demand for charging exceed 750 TWh in 2030. Secondly, according to the forecast of relevant agencies, by 2026, the anticipated installed capacity of solar photovoltaic power generation is set to surpass that of natural gas, and by 2027 will exceed coal. In the next five years, the installed capacity of solar photovoltaic power generation will maintain an annual growth trend. The application of solar energy in the transportation sector is growing, contributing to reducing carbon emissions, improving energy efficiency and promoting sustainable transportation.

The reason why solar energy can become a key area of energy transformation in the transportation sector is inseparable from its own advantages. (1) Solar energy is a zero-emission form of energy. Employing solar energy as a power source for transportation can substantially mitigate the greenhouse gas emissions produced by vehicles, thereby reducing the impact on global climate change. (2) Solar energy has the characteristics of decentralization, which can reduce the dependence on traditional energy sources such as imported oil and enhance the stability and security of the energy supply. (3) Solar energy is a widely distributed and renewable energy resource. The full use of solar energy to power vehicles can reduce the need for limited non-renewable energy sources and achieve sustainable development [13].

But at the same time, there are still many drawbacks to the use of solar energy. The first is the variability and intermittency of solar energy, solar power generation is affected by sunshine conditions, so there are variability and intermittency problems. During cloudy days, at night, or at high latitudes, the supply of solar energy is reduced or interrupted, which poses a challenge to a stable energy supply in the transportation sector. Secondly, the energy density of solar energy is relatively low, especially compared to traditional fuels. This means that more solar equipment is needed to obtain an energy supply comparable to that of fuel oil, especially for high-energy vehicles such as aircraft and large cargo vehicles, which may not be able to meet demand. And solar-powered vehicles typically take longer to charge or store energy than conventional gas-powered vehicles. This can be inconvenient for some application scenarios, such as long-distance travel and high-intensity commercial transportation. The Shockley-Queisser limit is determined by evaluating the electrical energy harvested per incident photon. The calculation shows that the maximum solar energy conversion efficiency is about 33.7%, so the solar energy conversion efficiency is low. Current solar energy conversion technologies still face the challenge of relatively low conversion efficiency. Although the efficiency of solar cells continues to improve, there is still a large amount of solar energy that is not effectively converted into usable energy.

5. Conclusion and prospect

The energy transformation of transport systems is a major problem that needs to be solved on a global scale. This research mainly introduces the utilization of lithium batteries, hydrogen fuel cells and solar energy in the transportation system, which provides key solutions for promoting sustainable development. First, the rapid development of lithium battery technology makes electric vehicles possible. Lithium batteries offer the benefits of high energy density, extended cycle life, and superior power output, and have gradually become the main choice to replace traditional fuel vehicles. Electric vehicles powered by lithium batteries can not only reduce dependence on fossil fuels and reduce carbon emissions, but also improve traffic efficiency and improve air quality. Second, hydrogen fuel cells also have great potential as another clean energy transition option. By reacting hydrogen with oxygen to produce water and electricity, vehicles propelled by hydrogen fuel cells solely discharge water vapor. Compared to lithium batteries, hydrogen fuel cells have higher energy density and longer driving range, while charging time is relatively short. However, the storage and distribution of hydrogen remains a challenge that requires more infrastructure and technological improvements. In addition, solar energy, as a renewable energy source, is also gradually applied to transportation systems. Solar panels convert sunlight into electricity to power electric vehicles. The use of solar energy in transportation systems can not only reduce reliance on traditional power systems but also reduce carbon emissions. Through the solar charging pile, the driver can easily charge the electric vehicle for daily use, improving the convenience of sustainable travel.

In summary, lithium batteries, hydrogen fuel cells, and the usage of solar energy play an important role in the energy transformation of transportation systems. They are environmentally friendly, efficient, and renewable, making a positive contribution to sustainable development. However, each energy transition technology has its own advantages and challenges and requires governments, businesses and all sectors of society to work together to promote technological innovation and infrastructure development. Only through global cooperation and joint efforts can the process of energy transformation of transport systems be accelerated to create a cleaner and more sustainable future for humanity.

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