



Conference Article

A Comparison of Battery and Hydrogen Fuel Cell Electric Vehicles for Clean Transportation

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Abstract

Burning fossil fuels for transportation is a major source of greenhouse gas emissions, which contribute to global warming, air pollution, and health problems. Research estimates that cars alone emit more than 300 million tons of carbon dioxide into the atmosphere each year due to the internal combustion engines that use fossil fuels. In contrast to fossil fuel vehicles, electric vehicles have zero tailpipe emissions. Therefore, countries around the world are making efforts to use electric vehicles instead of fossil fuels. Two of the available alternatives to internal-combustion engines are battery and hydrogen fuel cell electric vehicles. This work investigates the basic functionalities and current advancements of battery and hydrogen fuel cell electric vehicles. A comprehensive comparison of the benefits and drawbacks of each technology is provided, along with future forecasts for transportation.

Keywords: Transportation, battery electric vehicle, hydrogen fuel cell electric vehicle, greenhouse gas emission

1. Introduction

Today, almost 95% of the global land-based transportation sector is provided by fossil fuel vehicles. The greater part of these fossil fuels is comprised of diesel and gasoline. 77% of total transportation consumption was accounted for by these petroleum products. According to the U.S. Environmental Protection Agency, fossil fuel vehicles used in



global transportation are responsible for approximately 14% of the greenhouse gas emissions such as carbon dioxide (CO₂), nitrous oxide (N₂O), methane (CH₄), and other harmful particles and CO₂ is the primary source among the greenhouse gases as shown in Figure 1. The increase in the number of fossil fuel vehicles has led to some major concerns, including environmental pollution and global warming. Furthermore, greenhouse gases not only contribute to climate change but also have long-term impacts on human health. Besides, the world's fossil fuel sources are limited, with oil expected to run out in roughly 50 years [1].

Electric vehicles are the most significant alternative to conventional fossil fuel vehicles. Governments are encouraging the use of electric vehicles with zero-emission values. Hence, electric vehicles have experienced a tremendous rise in production over the past ten years due to growing interest around the world. Electric vehicles are much more efficient than conventional vehicles since they can convert around 62% of battery energy into mechanical energy while conventional vehicles with internal combustion engines only use 21% of the available energy from fossil fuels. Since electric vehicles emit fewer greenhouse gases and air pollutants into the atmosphere, they are better for air quality. World Health Organization estimates that more than 4.5 million people die each year from air pollution-related causes which is more than the number of people who died in traffic accidents. In addition to that, the noise pollution caused by fossil fuel vehicles we are exposed to in cities can cause stress-related mental illnesses [2]. From this perspective, the main components of battery electric vehicles and hydrogen fuel cell electric vehicles will be presented and compared in this study.

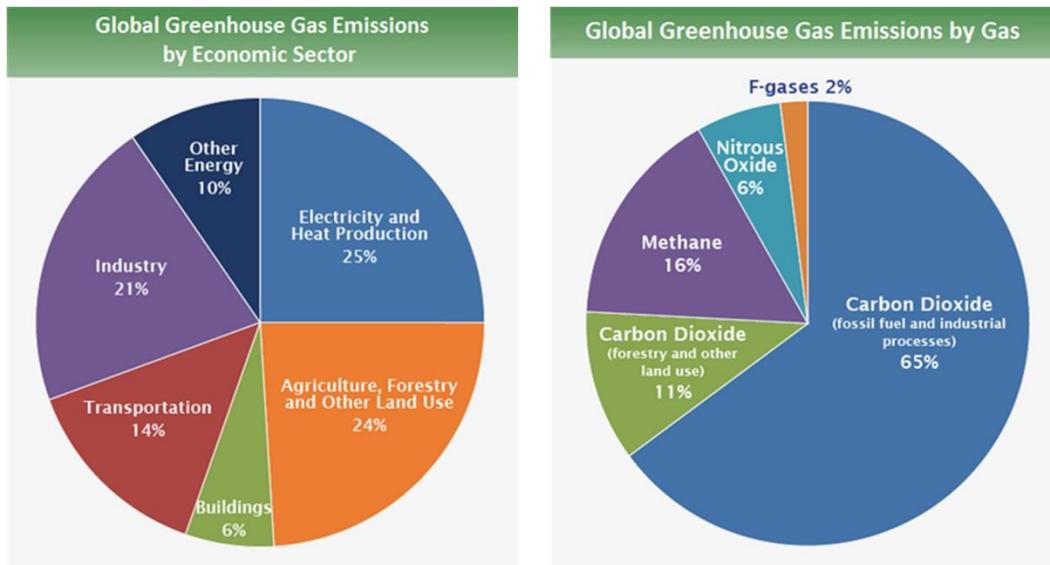


Figure 1: Global Greenhouse Gas Emissions by Sector and by Gas

2. Battery Electric Vehicles

An electric motor, as opposed to a conventional internal combustion engine, provides propulsion for battery electric vehicles powered by a high-voltage battery pack. Battery electric vehicles that comprise the battery pack, the inverter, and the electric motors get their traction from electric motors as presented in Figure 2. The DC-AC converter (also known as a motor controller) analyses the input signal and determines how much battery pack power is required when the accelerator pedal is pressed. Depending on how strongly the pedal is pressed, the controller then transfers a certain quantity of electrical energy to the motor. Through the use of electromagnets, the motor can transform the electrical energy it receives into mechanical energy. Inside the transmission which adjusts the speed of the rotation, the motor's output shaft makes a rotational movement causing the wheels to turn [3].

Since electric vehicles do not have mechanically moving components, they are much simpler and more efficient than conventional vehicles. Rechargeable lithium-ion batteries are now the most common type of battery used in electric vehicles because of their small size and high battery capacity. They are typically charged by an external power source, like a typical 220-volt outlet. The incoming AC electricity is converted into DC electricity by the onboard charger so that it can be used to charge the main battery. The power is sent to the traction motor, which is responsible for turning the wheels of the vehicle. Different high-tech electronic parts are used in this process. While the battery is being discharged or charged, lithium ions are carried by the electrolyte from the cathode to the



anode and vice versa. This movement of ions results in the generation of an electron current [3-4].

A battery management system must be included for every battery power pack. This device is essential for the vehicle's safe and stable performance. Today, the range of an average battery electric vehicle is about 300 km on a single charge depending on the battery type, the weight of the vehicle, and the driving circumstances. In general, the range of all-electric vehicles is significantly less than the range that equivalent conventional vehicles. This gap is being closed due to the ongoing advancement of high-powered charging technology. Besides, regenerative braking is an additional feature of battery electric vehicles. This technology is effective because it recovers some of the motion energy that would normally be dissipated during braking. In comparison to highway driving, city driving is more efficient for battery electric vehicles. In city driving, there are more frequent pauses, which optimize the advantages of regenerative braking, but on the highway, faster speeds usually need more energy to overcome the increased frictional force between the road and the tire.

The duration of a battery is affected by temperature, application, and state of charge. Although the generation of energy contributes to air pollution, battery electric vehicles are classified as zero-emission vehicles since they emit no direct tailpipe emissions [5].

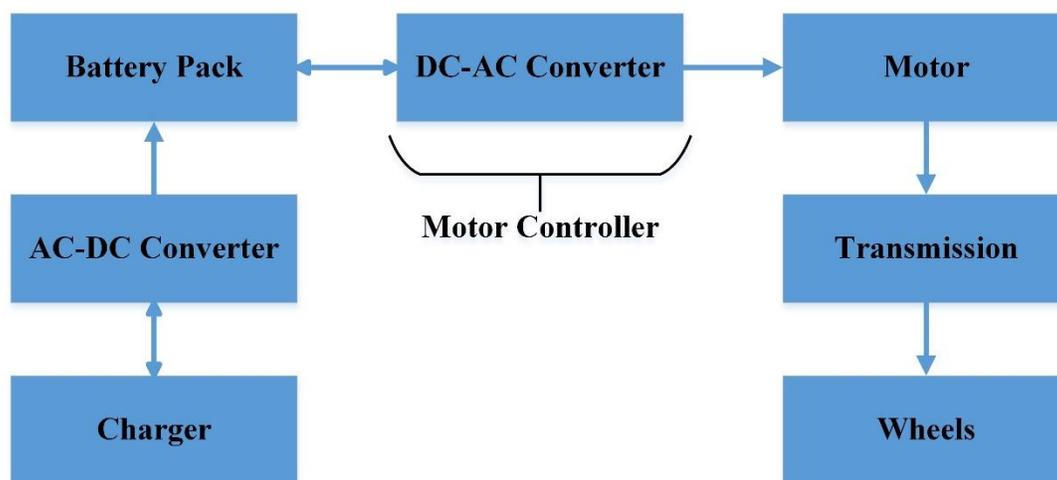


Figure 2: Working Principle of a Battery Electric Vehicle

3. Hydrogen Fuel Cell Electric Vehicles

In contrast to conventional battery electric vehicles, hydrogen fuel cell electric vehicles generate their energy using a fuel cell powered by hydrogen, as opposed to relying completely on batteries. As a main energy source, hydrogen is used for fuel cell electric



vehicles. They generate no pollutants from the exhaust and emit no greenhouse gases into the atmosphere, making them more energy efficient than internal combustion engines [6].

As depicted in Figure 3, the propulsion technique is comparable to that of a battery electric vehicle, with hydrogen being transformed into electricity. The hydrogen gas is stored in the hydrogen tank until it is required by the fuel cell stack, which is located inside the vehicle. A fuel cell stack is a device of separate membrane electrodes that combine hydrogen and oxygen to generate electricity. DC-DC converter transforms higher-voltage DC power coming from the fuel cell stack into the lower-voltage DC power required to operate the electronics and recharge the battery of the vehicle. The DC-AC converter controls the motor's speed and torque by regulating the flow of electrical energy generated by the fuel cell stack and the battery. As a result, the rotation of the wheels is performed and the vehicle is driven by the electric motor.

The polymer electrolyte membrane (PEM) fuel cell where an electrolyte membrane is positioned between the cathode and anode, is the most popular kind of fuel cell used in hydrogen fuel cell electric vehicles. The cathode receives oxygen from the air, whereas the anode receives hydrogen from the hydrogen tank. An electrochemical process takes place in the fuel cell stack, causing the hydrogen molecules to split into protons and electrons. After that, the protons pass through the membrane and are transported to the cathode and the electric vehicle is powered by electrons being pushed through an external circuit, with the electrons eventually recombining the protons on the cathode side to generate an H₂O molecule. As a result of the interaction between the protons, electrons, and oxygen molecules, only heat and water vapor are released into the atmosphere from this process. Several catalysts that are nano-sized particles can be used with various hydrogen fuel cell designs. Fuel cells are very effective since chemical energy does not have to be transformed into thermal energy and mechanical energy. Fuel cells reduce pollution in two ways, they produce fewer carbon emissions than conventional internal combustion engines and they waste less energy in the form of heat. Due to many positive aspects, fuel cells can be used in a broad variety of applications, from huge facilities like power plants to transportation [7-8].

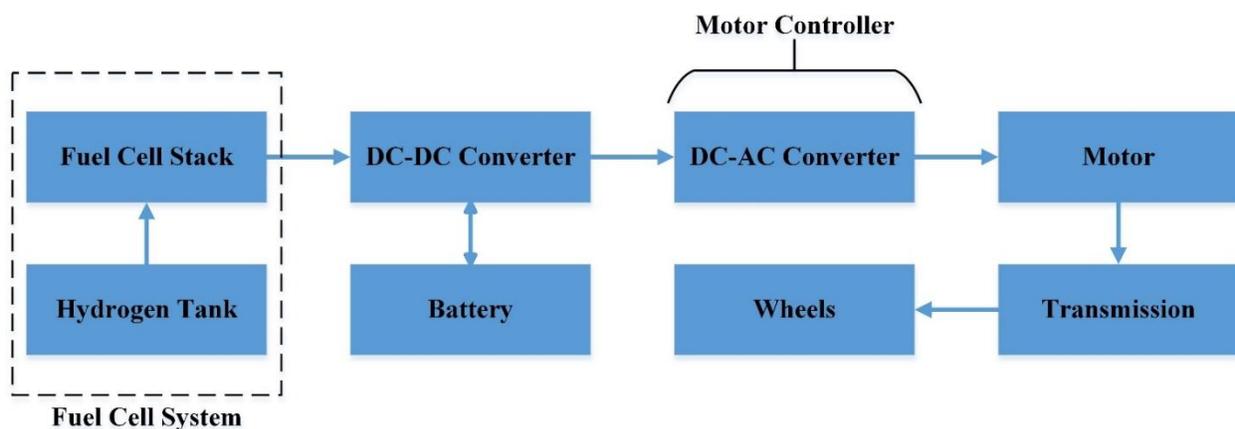


Figure 3: Working Principle of a Hydrogen Fuel Cell Electric Vehicle

4. Comparison of Battery and Hydrogen Fuel Cell Electric Vehicles

Battery and hydrogen fuel cell technologies are two possible options when converting chemical energy into electrical energy for generating electricity to drive electric vehicles. As shown in Table 1, both technologies have advantages and disadvantages depending on their applications and can be used to run transportation on electricity for solving the clean energy problem [9]. In this section, the main differences between battery and hydrogen fuel cell technologies will be explained comparatively.

One major difference between batteries and hydrogen fuel cells is that fuel cells produce energy by converting readily available fuel, whereas batteries store energy for later use. While in battery electric vehicles batteries consisting of different chemical substances such as nickel-cadmium, sealed lead-acid, nickel metal hydride, and lithium-ion are used, in hydrogen fuel cell vehicles the required energy is obtained as a result of the chemical reaction of hydrogen and oxygen. Lithium-ion technology, which is the most used and low-maintenance kind of battery in today's many electronic devices, is frequently preferred in battery electric vehicles. Lithium-ion batteries are more advantageous than other rechargeable batteries due to their high energy density, good performance at high temperatures, and low self-discharge rate.

Batteries are indeed more energy-efficient than hydrogen fuel cells, but the weight difference becomes significant when comparing the two for heavy-duty, long-range trucks. As hydrogen has a higher energy density than batteries, a powertrain that runs on hydrogen fuel cells can save some weight. As a result, hydrogen fuel cell technology enables greater range and more payload.

One of the most significant advantages of the hydrogen fuel cell over batteries is the need for refueling time. While recharging a battery in an electric vehicle could take hours, a



hydrogen fuel cell-powered vehicle could be back on the road in less than 10 minutes. Because of this, hydrogen fuel cell technology is excellent for vehicles that operate around the clock. In addition, hydrogen fuel cells are less affected by cold temperatures, therefore they can readily tolerate these fluctuations throughout a long drive. Batteries need much more maintenance to prevent downtime during operations of high demand.

Cost is another important and decisive factor when making a comparison between battery and hydrogen fuel cell technology. Today, the cost of each technology is more than that of a conventional car of the same type. The most significant contributors to the overall cost of fuel cell technology are the catalyst components. Many studies have shown that batteries are less attractive due to their larger size, higher weight, and cost when compared to hydrogen fuel cells. On the other hand, infrastructure, distribution, and accessibility are big challenges for hydrogen fuel cell technology, especially in the transportation sector.

Although the purchase price for both battery and hydrogen fuel cell electric vehicles is higher than the conventional vehicles with internal combustion engines, they offer big savings in the long-term due to the fuel savings and low maintenance costs. In addition, it is not difficult to predict that prices of battery and hydrogen fuel cell technology will be affordable in the near future due to technological innovations being performed in this field.

Table 1: Advantages and Disadvantages of Battery and Hydrogen Fuel Cell Technologies

Fuel Type of the Vehicle	Advantages	Disadvantages
Battery	<ul style="list-style-type: none"> Powerful and energy efficient Reduced maintenance expenses No tailpipe emissions Smooth and silent driving 	<ul style="list-style-type: none"> Demand for rare metals Recharging takes long Lack of public charging facilities Not suitable for long-distance travel
Hydrogen Fuel Cell	<ul style="list-style-type: none"> Renewable and readily available source Highly efficient No tailpipe emissions Reduced refueling time 	<ul style="list-style-type: none"> Higher cost of raw materials Hydrogen extraction process Lack of hydrogen refueling infrastructure Highly flammable

5. Conclusion

In recent years, the rapid growth in greenhouse gas emissions due to the use of fossil fuels has caused significant damage to the environment and human health around the world. Besides, fossil fuels are non-renewable energy sources and are estimated to run



out soon. As a result, fossil fuel-powered vehicles are being replaced by renewable electricity. Among the alternatives to internal combustion engines, battery electric, and hydrogen fuel-cell motors stand out due to their several advantages. Although the majority of automakers have moved their attention to battery electric vehicles, both technologies have benefits and drawbacks and can be used to run vehicles on electricity to solve the clean energy challenge.

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