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Hydrogen on the Horizon

On March 20, 2023, climate experts released the final installment of the Intergovernmental Panel on Climate Change's (IPCC) Sixth Assessment Report (AR6). The report details not only the consequences humanity can surely expect to come if action is not taken but also the devastating catastrophes millions of people around the world already face. However, among the several reports related to climate change, only about 200 studies specifically detail what can be done to mitigate the crisis. Scientists are not the only ones hard at work to research and combat climate change, engineers in the automotive industry have also made advancements in their field to ensure that transportation - an extremely important facet of modern society - becomes cleaner and more sustainable for the environment. Of all the efforts to engineer both sustainable and efficient vehicles, hydrogen fuel cell vehicles (HFCVs) are the better alternative since these vehicles are a promising prospect in terms of their environmental friendliness, evolving technologies, and potential to "power" more livable communities.

Sustainable Fuel Production and Lower Greenhouse Gas Emissions

To begin with, HFCVs are overall a cleaner and more efficient method of transportation due to the nature of hydrogen fuel cells. In the world of hydrogen fuel cells, polymer electrolyte membrane fuel cells (PEMFCs) are the most commonly applied and thus the ones with the most literature. At the negative side of a PEMFC, or the anode, hydrogen from a storage unit flows in. After coming into contact with an electrolyte, the hydrogen atoms separate into protons and electrons. However, because only the positive hydrogen ions can pass through the electrolyte and directly to the cathode, electrons are driven to an alternate path around the membrane in order to rejoin with the protons, generating current. At the cathode, the protons recombine with the electrons and react with oxygen from the air. This means that the only byproduct of these fuel cells is water or H_2O. Interestingly enough, this process can be reversed in another process called electrolysis. In the electrolysis of water, an electrical current separates water molecules into hydrogen and oxygen gas at the electrodes. Both of these processes are emissions-free, meaning that combined with electrolysis powered by renewable electricity, hydrogen fuel cells shape up to be the cleanest method of yielding power in vehicles. In this manner and including other factors, the most CO_2 emissions put out by HFCVs in both fuel production and consumption combined are “11.9 kg CO_2 per 5 kg Tank Hydrogen” (Wong et al. 10). In contrast, the total CO_2 emissions in the same area in ICEVs and plug-in hybrid electric vehicles (PHEVs) are 238 kg CO_2 and 121.8 kg CO_2 respectively (Wong et al. 10). Additionally, reducing carbon emissions is not the only environmental benefit to investing in HCFVs. Producing hydrogen for its respective fuel cells can also tackle the plastic pollution problem. In an experiment conducted by Jie et al., researchers found that microwaving a mix of iron oxide and aluminum oxide (FeAlOx) with a ground-up assortment of plastics can yield 55.6 moles of H_2 per gram of plastic waste (compared to a theoretical maximum of 71.4 mmol $g^{-1}_{plastic}$), garnering a hydrogen efficiency of 97% (906). Compared to other methods of pyrolysis (a process using heat to decompose materials, typically without oxygen), not only is this method several times more efficient, but it is also emissions-free, with what would normally be yielded as CO_2 instead taking shape as carbon nanotubes (Jie et al. 902). Overall, having more HFCVs on the road instead of ICEVs and battery PHEVs would not only decrease the number of CO_2 emissions but also the increased demand for hydrogen production has the potential to push back against plastic pollution.

Advancements in HFCV Technology and Implementation

Furthermore, hydrogen fuel and HCFVs as emerging technologies have challenges in dealing with fuel production and storage that are promptly being improved upon. In regard to production, although electrolysis is the most appealing method because of its sustainability, the process is not as efficient as it could be and is more costly. Most commercial electrolyzers require approximately 1.8 volts and consume around 48 kilowatt-hours of energy to make 1 kg of hydrogen, which translates to almost 40 kWh of energy (Hodges 2, 6). The International Renewable Energy Agency's (IRENA) target energy consumption for H_2O electrolysis by 2050 is <42 kWh, but a capillary-fed electrolyzer (CFE) engineered by Hodges et al. has already topped this target at around 40 kWh, boasting an efficiency of about 98%, which is 15% more efficient than the commercial models (6). Meanwhile, pertaining to storing hydrogen fuel in HFCVs, the most concerning drawbacks are low hydrogen density, safety, and practicality. Because of low hydrogen density, most onboard hydrogen fuel tanks would have to be larger in size (Hosseini and Butler 15). In "Hydrogen Fuel Cell Vehicles; Current Status and Future Prospect", Manoharan et al. recognize three major hydrogen storage systems: pressurized tank storage, metal hydration, and cryogenic liquid hydrogen storage (3-4). While pressurized tank storage can hold its ground against collisions (Manoharan et al. 3), these systems do not inspire confidence due to the devastating consequences of a gas leak in a highly pressurized tank (Baptista et al. 3). Metal hydration involves storing hydrogen in metal compounds as an alloy inside a vehicle, but these systems are generally too heavy, expensive, and high-maintenance to be practical (Manoharan et al. 4). Finally, liquid hydrogen also has the same challenges as metal hydration, except it also has the potential to become explosive if it reacts with other gasses, making it more expensive and high-maintenance (Manoharan et al. 4). Baptista et al. recognized these critical issues and designed a new storage method with an emphasis on optimizing the gravimetric energy density (GED) and volumetric energy density (VED) of the system and decreasing the risk of an explosion due to high pressure. In this model, hydrogen is stored within spheres with both a structural layer and a liner, which are made of CFEP and aluminum respectively to prevent hydrogen leakage (Gustavo et al. 13). Microchips made of silicon control whether the spheres fill with or release hydrogen for consumption based on a pre-programmed threshold and user needs (Baptista et al. 5). According to Gustavo et al., the GED and VED, or the ratio of energy to weight and volume, respectively, is the most efficient in this proposed storage system (3). The packing factor contributes to the maximum number of spheres, and therefore hydrogen, the storage unit can contain, thus influencing these numbers (Gustavo et al. 9). Overall, these efforts show that the future of HFCVs has the potential to keep evolving and becoming more efficient and practical to be a part of our lives thanks to these innovations.

Hydrogen Fuel Cell Heavy-Duty Vehicles and Implications for Society

Lastly, while most literature surrounding HFCVs emphasizes their applications in light vehicles, the potential of HFCVs shines in heavy-duty vehicles (i.e. buses, large trucks, trains, etc.). Hydrogen fuel cells are capable of lasting longer and recharging for shorter times, and the bigger space needed for storage systems due to hydrogen's lower energy density is not as pervasive of an issue if the vehicle itself is larger than average (Trencher and Achmed 2). Also, of the two most popular hydrogen fuel methods, which are hydrogen fuel cells and internal combustion engines, fuel cells are in favor to be the most common form of powering heavy-duty hydrogen-powered vehicles thanks to higher tank-to-wheel efficiency, no carbon emissions, and "reduced operating noise" (Pardi et al. 2). Essentially, hydrogen fuel cells would be a perfect fit for implementing more sustainable public transportation in the form of buses and trains. Public transportation not only aids in sustainability but also livability. Having accessible public transportation would reduce the need for cars on the road, which not only alleviates traffic but in doing so promotes walkability and livability. A survey conducted on residents of Doha, Qatar found that many residents are fearful of passing cars and "frequent driver violations of neighborhood speed limits", causing a lack of places where children can play in their own city. (Al-Thani et al. 13). However, many people still expressed they were not opposed to the idea of walkability (Al-Thani et al. 13). According to Al-Thani et al., livability, is a key component of sustainability because "communities cannot be sustainable unless they create a place/environment where people perpetually want to live." (7). Thus, promoting both greener and more livable transportation would not only improve global health but also the well-being and fulfillment of several generations, including children.

In conclusion, HFCVs are a good investment for research facilities and policymakers because of the environmental benefits, emerging technological advancements, and shaping a more humanitarian world. Hydrogen fuel technology is the most sustainable and least harmful to the environment by far due to the engineering behind them, and the infrastructure supporting it that will keep evolving as a part of the very same engineering process. Finally, the implementation of hydrogen-powered public transportation not only sees improved efficiency, but an improved lifestyle for communities across the world.

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