Advantages and Disadvantages of Hydrogen Trains

Subjects: Energy & Fuels | Transportation
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Hydrogen and electric drives used in various means of transport is a leading topic in many respects.

Keywords: energy transformation ; energy consumption ; climate policy

1. Introduction

Drive Efficiency

Electric drives are used in various means of transport. The most common application is public transport, i.e., passenger cars [1], trams, trolleybuses [2], and buses, electric multiple units [3] or cycles [4]. Similarly, the aviation industry is considering the use of electrical technology and power electronics in cargo aircrafts [5]. Cars for the transport of goods (trucks) with electric drive did not go beyond the research area. However, passenger cars have entered the market quite recently. However, hydrogen-powered means of transport (FC) appeared about two decades ago. This drive is most often used in rail passenger transport, e.g., Siemens Mireo Plus H and Alstom Coradia iLint, and is currently used for passenger transport. Passenger cars equipped with fuel cells, although they are already in production (Toyota Mirai, Honda FCV Concept, Roewe 950 Fuel Cell, Audi Sportback A 7 h-tron Quottra, Hyundai Tucson Fuel Cell), are still not widely used.

In an internal combustion engine, the energy contained in the fuel (gasoline, oil, LPG) is converted into useful work [6]. Unfortunately, conversion of the form of energy into the engine is associated with a number of losses. First, an insignificant fraction of the fuel is not converted into ideal combustion products. In turn, the second law of thermodynamics states that only a small part of this energy can be converted into useful work. It is related to the thermodynamic efficiency and the change of heat in the work [7]. The energy of combustion is largely lost as a result of heat dissipation in conjunction with hot combustion gases, as well as thermal radiation and heat transfer [8] through the surfaces of the combustion chamber [9].

In these devices, the chemical energy of the fuel is converted into electrical energy with a theoretical efficiency of 83% [10]. Among the many advantages of fuel cells, it is worth highlighting the following [11]:

- unlike engines operating on the basis of the Carnot cycle, the maximum efficiency of energy conversion in fuel cells is at non-zero power;
- pure water is the product of conversion of chemical energy of hydrogen into electricity;
- electricity generation in applications with power ranging from milliwatts [mW] to megawatts [MW] is continuous, as long as substrates for electrochemical reactions are supplied.

2. Benefits

Hydrogen-powered trains have many features that make them ideal for reducing carbon emissions:

- No emission of substances other than water vapour;
- Hydrogen is plentiful and can be produced from renewable energy;
- Short refuelling times;
- Their potential as a two-mode train, which means that they can run on both electrified and conventional lines;
- Better fuel consumption, more efficient? It is probably about engine efficiency;

- No engine noise or visual pollution;
- There are no disturbances in the entire network due to the lack of infrastructure for electricity transmission.

3. Disadvantages

The use of hydrogen fuel cells presents a number of challenges:

- The technology is currently expensive (investments required);
- Most of the energy used in the hydrogen extraction process currently comes from non-renewable sources;
- It requires storage of hydrogen under very high pressure on board (danger?);
- There are few places for refuelling, the need to expand the network;
- The hydrogen installation, which is currently located, for example, in the EMU, limits the number of people who can board the car;
- Currently, hydrogen trains are still dependent on virgin hydrogen and infrastructure.

To replace the current energy carriers with hydrogen, it is necessary to develop a cheap, fast and efficient method of its production [12].

Currently, research and development work on trains powered by hydrogen fuel cells is focused primarily on increasing the capacity (storage capacity) of hydrogen and developing new LTO (lithium-titanium-oxide) batteries with high energy density, the working time of which will be about 15 years. In addition, scientists are focusing on increasing the power density of fuel cells, extending their lifetime and lowering LCCs. An important aspect of the operation of hydrogen-powered trains is the DC/DC converters for fuel cells built using SiC technology. The use of this technology already allows reducing the weight and dimensions of the device and finally reducing energy consumption by 30%, also due to the use of supercapacitors [13].

The common use of electric cars and the replacement of cars with combustion engines with them would have to be preceded by the preparation, i.e., the construction of a very dense current infrastructure necessary to charge the batteries. Of course, in addition to the charging station, this would require connecting each station to the power line and building new power plants that would continuously generate the electricity needed to power electric cars.

It is also important to answer the question of where and how electric cars will be charged by city dwellers who live in multistorey blocks of flats.

The currently functioning multi-storey car parks in city centres (but also in the vicinity of shopping centres located on the outskirts of cities) are not designed to carry such a mass of cars. The weight of the battery in an electric car is min. 700 kg (and, for example, that in a Tesla Roadster 2 is about 0.8–1.2 tons); then, parking the same number of cars in previously built car parks will result in a construction disaster.

The price of electric cars is so high that most people will not be able to afford a new electric car. Unlike cars with a combustion engine, electric cars that are already 5–6 years old are not interested in buyers, because every potential customer is aware that in a moment, the entire battery pack will have to be replaced, the cost of which is more than half the price of a new car. For example, Tesla Model 3 battery replacement in 2020 was USD 15,800. However, older electrics, such as the 2017–2018 VW e-Golf, will cost USD 23,443 (2021) to replace the battery pack and USD 20,000 for the 2014 Tesla Model S (December 2020) [14].

As reported by the media around the world, electric cars tend to self-ignite, although electric car fires are quite rare; according to statistics, they are only 0.03% of all car fires (1.5% of gas cars or 3.4% of hybrid cars) [15]. However, a car is difficult to extinguish, and the firefighting action may even last several hours (sometimes even more than 20 hours). Furthermore, even these extinguished cars have a tendency to self-ignite again. What will happen when one of them starts to burn in an underground parking lot full of electric cars? The result will probably be a disaster. The garage will be demolished after such a fire, but with luck, no people will be killed or injured.

Recently, the Norwegian ferry line Havila Kystruten announced that it will not allow electric, hybrid and hydrogen cars on board, although the Havila Capella ferry is equipped with a low-emission hybrid drive consisting of engines powered by LNG (liquefied natural gas), coupled with an electric drive powered by giant batteries weighing 86 tons and with a capacity of 6.1 megawatt hours, which allows for several hours of emission-free cruises. Perhaps concern for the safety of passengers is the reason for this decision [16].

The ban on the entry of electric cars into underground parking is related to the danger and risk of fire. This ban was issued by the administration of the Warszawianka swimming pool and applies not only to electric-powered cars, but also hybrid and gas-powered ones. The decision is conditional on the fact that "the underground garage is located directly under the sports swimming pool basin, and any potential fire caused by self-ignition of the traction battery in an electric or gas-powered vehicle will completely destroy the water supply and treatment system of the swimming pool made of PVC suspended from the ceiling of the garage. Additionally, the high combustion temperature can permanently damage the poles supporting the swimming pool basin and, as a result, suspend the activity of the swimming pool" [17].

Hydrogen-powered cars have the advantage that they do not need a battery, as electric cars do. The problems with obtaining lithium and cobalt (in such an increased amount) mentioned in this publication automatically disappear.

Certainly, replacing cars with internal combustion engines with cars with an electric or hydrogen engine will make the state independent from the supply of crude oil or its derivatives. The electricity needed for electric cars or electrolysis to obtain hydrogen will not come from the combustion of fossil fuels because dependence on fossil fuel suppliers will still remain, and thus, the argument about environmental protection by electric or hydrogen cars loses its raison d'etre.

Another possibility exists in the form of a hydrogen internal combustion engine vehicle (HICEV), which is a type of hydrogen vehicle that uses an internal combustion engine. Hydrogen internal combustion engine vehicles are different from hydrogen fuel cell vehicles (which use electrochemical use of hydrogen rather than combustion). Instead, the hydrogen internal combustion engine is simply a modified version of the traditional gasoline-powered internal combustion engine [10][11]. The absence of carbon means that no CO_2 is produced, eliminating the main greenhouse gas emission of a conventional petroleum engine.

Currently, the efficiency of FCS (Fuel Cell System) hydrogen cars in terms of usable electrical energy is lower (about 50%) than that of the lithium-ion battery (about 90%), although the range of the Hyundai Nexo equipped with 3 hydrogen fuel tanks is 666 km (in the WLTP cycle—Worldwide Harmonised Light vehicles Test Procedure). In addition, hydrogen is simple and much faster than charging electric vehicles. At the same time, FCVs are very safe, even in the event of a car accident—the Hyundai NEXO scored five stars in the Euro NCAP safety test. Of course, replacing cars with combustion engines with FCS cars also requires the construction of infrastructure, but in this case, it is enough to build the appropriate tanks for safe hydrogen storage in existing petrol stations [18].

Thanks to an appropriate economic strategy, the fuel cell (FC) can become a more advantageous alternative for use in cars, trucks and buses (electric cars). The hydrogen fuel cells will play an important role in the transport industry in the near future. In the near future, fuel cell prices should record a downward trend in terms of mass production and their widespread commercialisation [19].

The analysis of available literature data, taking into account all aspects and stages of production of electric cars and their most important components, such as lithium-ion batteries, shows that electric cars are not ecological. Obtaining lithium is associated with the degradation of the natural environment, the use of toxic chemicals that must be disposed of and the very high consumption of drinking water. The extraction of cobalt is often associated with the use of child labour. Finally, people currently do not have any idea how to manage used batteries. Therefore, the most important argument for their use, which is the protection of the natural environment, is a lie. Very often, it results from the ignorance of those who use this argument. Further, the hydrogen drive will be truly ecological if the hydrogen used is not a product of burning fossil fuels.

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