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Comparative Assessment of the Prospects for Hydrogen Fuel Cell Electric Vehicles

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ABSTRACT

Today, road transport is one of the main environmental pollutants. It accounts for more than half of all emissions. In this regard, the issue of developing measures to reduce the impact of cars on the environment is gaining relevance. There are various approaches to solve this issue, but the most promising direction is the use of electric vehicles. It should be noted that we cannot talk about their absolute environmental friendliness, since there is still an indirect impact on the environment.

The paper examines the prospects for the use and disadvantages of two types of electric vehicles powered, respectively, by battery or hydrogen fuel cells.

Currently, production of battery electric vehicles is a more popular direction, which is largely due to development of technologies in the field of battery production. At the same time, one should not completely exclude other areas, such as hydrogen-fuelled vehicles. Such vehicles are distinguished by good environmental friendliness, which is determined by the nature of the combustion product and the possibility of obtaining this type of resource. However, the use of hydrogen as a fuel for internal combustion engines is not relevant. Development of a car with an electrochemical generator is more promising. Today, a fairly large number of the world's leading car manufacturing companies are advancing in this direction.

The electric vehicles considered in the work have similar emissions of harmful substances, which, under equal conditions, approach zero. However, both types of vehicles leave a carbon footprint, the bulk of which comes from electricity generation and hydrogen production. The study carried out a comparative assessment of the quality characteristics, carbon footprint and operating costs of electric vehicles with various types of power plants under Russian operating conditions. Based on the comparison, the main advantages, and disadvantages of those types of electric vehicles have been identified. Actions are proposed to increase the environmental friendliness of electric vehicles and solve problems that complicate their operation.

Keywords: road transport, electric vehicle, emissions reduction, hydrogen vehicle, environmental friendliness, comparison.

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INTRODUCTION

The fleet of vehicles with internal combustion engines (ICE) in the regions of Russia is increasing. This category of cars produces large amounts of harmful emissions, which negatively affect the environment. It is known that the predominant part of all emissions comes from road transport, so this problem is most acute in large cities [1]. To solve this problem, the relevance of the issue of developing a set of measures aimed at reducing emissions from cars is increasing. Most of the leading car manufacturing companies are interested in solving this problem. For example, Tesla Motors has developed its own electric vehicles and is also improving the system of environmentally friendly electric charging stations. Toyota Motor Corporation has succeeded in creating efficient hybrid cars and electric vehicles [2, 3].

Pic. 1 presents the main methods for reducing the impact of cars on the environment.

One of the most promising methods for reducing harmful emissions produced by vehicles is the use of electric vehicles with different energy sources: hydrogen fuel cells and electric batteries. This is due to the fact that an electric vehicle does not have a direct impact on the environment and amounts of emissions depend on the method of producing electricity or hydrogen [4].

It should be noted that there has been a significant increase in the popularity of development of electric vehicles among car manufacturers. This is largely due to scientific advances in the field of electricity storage, namely to improvements in the capacity and service life of batteries [5].

It is also worth noting the possibility of using hydrogen as fuel for a car. Hydrogen, first, is distinguished by its environmental friendliness, since the combustion product is water vapour; in addition, due to its nature, it is a renewable resource. Those two features constitute its main advantages.

The use of hydrogen in road transport is carried out in two ways [6]:

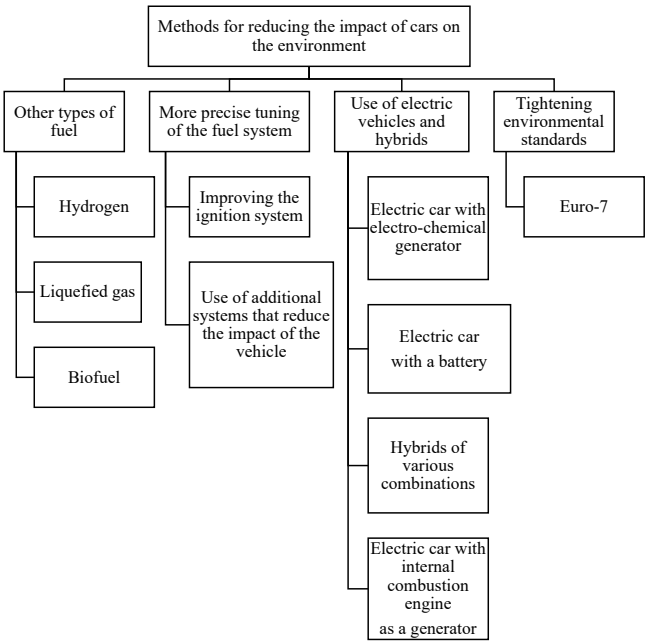
1. By burning it in a combustion chamber.

2. As a fuel cell: hydrogen is sent to an electrochemical generator, where it is converted into electrical energy to power an electric motor.

An internal combustion engine using hydrogen fuel has few differences from its analogue using petrol, but during its operation several difficulties arise:

– Hydrogen is more energy-intensive and has a higher calorific value, which is almost three times higher than petrol, which is why, at high speeds, overheating of engine parts, engine oil and detonation occur.

– On the other hand, since hydrogen has good characteristics at low speeds; to solve the above problem, a petrol-hydrogen mixture is used. In this case, the gas concentration decreases as the engine speed increases, and that results in a drop in the power and dynamic performance of the car [7].



Pic. 1. Methods for reducing the environmental impact of cars [performed by the authors].

Based on the above, the use of hydrogen as a fuel for internal combustion engines is not relevant, so the most promising is development of a car with an electrochemical generator. The principle of its operation is identical to the principle of operation of electric vehicles powered from the network, the main difference lies in the method of generating electricity. In electric vehicles with a hydrogen fuel cell, energy is generated through a physical and chemical reaction that occurs directly in the power unit.

Many leading global car manufacturing companies are engaged in development and design of more efficient electric vehicles. Thus, Toyota introduced the Toyota Mirai hydrogen electric car in 2015. In this car, electricity is generated in a generator due to interaction of hydrogen with oxygen. The vehicle is equipped with a traction synchronous electric motor, which is powered not only by fuel cells, but also by a nickel-metal hydride battery, which is recharged by recuperating braking energy [8].

Tesla equips its electric vehicles with an asynchronous electric motor, an inverter, and a lithium-ion battery pack, which are charged from an external source or from braking energy recovery. The operation of the power plant is to convert direct current from batteries into three-phase alternating current to power the electric motor; this task is performed by an inverter [9].

As a result of the above, it becomes relevant to compare the quality characteristics of electric vehicles powered by hydrogen fuel cells and batteries under Russian operating conditions.

Thus, the *objective* of the study, described in the paper, is the comparative analysis of the promising prospects and of disadvantages of two types of electric vehicles, namely of battery and hydrogen fuel cell electric vehicles.

RESULTS

Comparison of operation risks. Currently, battery electric vehicles are equipped with a lithium-ion battery, which undergoes, if one of the cells is damaged, a risk of a short circuit resulting in ignition of electrolyte, leading to a fire. It is not possible to extinguish such a battery: you will have to wait until the electrolyte burns out completely.

In an electric vehicle powered by a hydrogen fuel cell, the main danger is the container with compressed hydrogen, which is under a pressure of 700 atmospheres (due to the chemical properties of hydrogen it has the lowest liquefaction temperature and density). Currently, fuel tanks are made of carbon fibre materials that do not allow the release of fragments if the tank is damaged, which makes this type of vehicle the safest.

Comparison of the carbon footprint. The electric vehicles considered in this work have similar emissions of harmful substances, which, under equal conditions, approach zero. However, both types of vehicles leave a carbon footprint, the bulk of which comes from electricity generation and hydrogen production.

The analysis of statistical data has shown that about 26 % of air polluting emissions come from the energy industry, so it is rational to consider the environmental effect of electric vehicles, taking into account the emissions from electricity generation [10].

According to the International Energy Agency, thermal power plants account for about 60 % of all generated electricity obtained by burning carbon fossils: coal, gas, fuel oil (Pic. 2). It should be noted that this method of generating electricity has the greatest impact on the environment and is the «dirtiest». About 19 % of electricity is produced at hydroelectric power plants, which in turn contribute to destruction of the ecosystem in the places where it is located [11]. Nuclear power plants generate 17,5 % of the total electricity, and the share of power plants that generate electricity from alternative energy sources accounts for about 1,5 %.

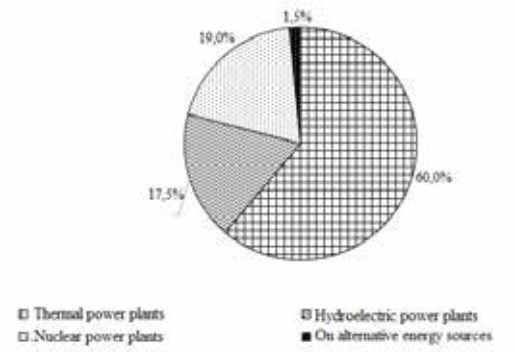
It should be noted that to obtain more reliable results, when carrying out calculations, it is necessary to take into account the main components that are used to produce hydrogen. Today, hydrocarbons predominate as raw materials for hydrogen production (Pic. 3) [13]:

– 69 % – natural gas;
– 15 % – oil;
– 11 % – coal;
– 5 % – electrolysis of water.

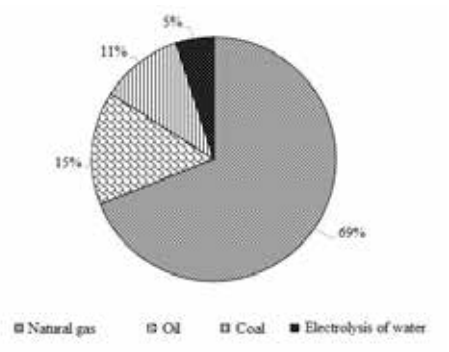
In addition, the resulting hydrogen is of three types [15]:

1. «Grey» – this type of hydrogen is produced through steam reforming of methane. The carbon footprint is 10 kg CO_2 per 1 kg of H_2 produced. The cost of production is 60–100 rubles.

2. «Blue» – the technology for producing this type of hydrogen is fully consistent with the technology for producing «grey» hydrogen. The main difference is the carbon capture and storage technology. The cost increases to 150 rubles per kilogram of hydrogen.



Pic. 2. World electricity generation [12].



Pic. 3. Raw materials used for hydrogen production [14].

3. «Green» – this type of hydrogen is produced through the electrolysis of water, using energy obtained from renewable energy sources. This is the most preferred method of production from the point of view of decarbonisation, since the carbon footprint tends to zero. The disadvantage is the high cost of production, reaching 1000 rubles per kilogram of hydrogen.

Thus, any type of electric vehicle leaves a so-called carbon footprint, which is characterised by amounts of emissions during the production and operation of the vehicle. Therefore, to determine the extent of the impact of an electric vehicle with different types of power plant, it is worth comparing the formation of a carbon footprint for an electric vehicle with a battery and for an electric vehicle with a hydrogen fuel cell at the time of operation of the vehicles, taking into account the emissions during production of fuel and the electric vehicle itself.

To assess the degree of impact of electric vehicles on the environment, calculations were made taking into account the efficiency of power plants, as well as the efficiency of converting energy carriers into fuel [16]. Operating a battery electric vehicle for 200 thousand km, using mixed energy sources, produces emissions equal to 23 tons of carbon dioxide equivalent. For the same mileage, if only alternative energy sources are used, the emissions will be 0,4 tons equivalent [17].

The average hydrogen consumption by an electric vehicle using a hydrogen fuel cell is 1 kg H_2/100 km^2, from this we can calculate the carbon dioxide equivalent emissions by averaging the emission readings for different types of hydrogen production.

Table 1 presents the results of assessing the formation of a carbon footprint by electric vehicles with, respectively, a battery and a hydrogen fuel cell during the operation of the vehicles. We can also note that the overall carbon footprint in Russian operating conditions from an electric vehicle powered by a hydrogen fuel cell is almost two times lower than that of a battery electric vehicle. It is worth noting that when using the cleanest method of extracting fuel for a power plant, emissions during hydrogen production tend to zero.

Operation costs. We will calculate operating costs for electric vehicles with a battery and electric vehicles with an electrochemical hydrogen engine.

The basis for the driving force of an electric vehicle is electricity. Based on this, for an electric vehicle with a battery, the calculation comes down to determining the cost of kWh, and for a hydrogen electric vehicle, to the cost of 1 kg of hydrogen.

Cost of a kWh is calculated based on the average home tariff for all regions of the Russian Federation: the average daily tariff is 3,45 rubles/kWh, the average night tariff is 1,68 rubles/kWh. [18]. The average day and night tariff is 2,57 rubles/kWh. We also consider that the average electricity consumption is 15 kWh/100 km. In addition, an electric car is highly susceptible to a decrease in range at low temperatures, that becomes approximately two times less than under ideal conditions, taking into account that there are 50 % of such days a year.

Currently, only one hydrogen car fuelling station is in operation on the territory of the Russian Federation, the cost of one kilogram of hydrogen at which is 250 rubles/kg [19].

Total fuel costs are presented in table 2.

We can note that fuel costs for a battery electric vehicle are almost six times lower than for a hydrogen one, this is due to underdevelopment of the infrastructure for hydrogen electric vehicles. When the paper was written, there was only one hydrogen fuelling station on the territory of the Russian Federation. This factor directly affects

Table 1

Results of assessing the carbon footprint of an electric vehicle with a battery and of an electric vehicle with a hydrogen electrochemical engine [performed by the authors]

Emissions by different types of energy system	Mileage of electric vehicles, thousand km					
	50		100		200	
	Battery		Battery		Battery	
Russian operating conditions, t	7	3,750	14	7,5	28	15
Wind energy and green hydrogen, t	1	0,01	2	0,02	4	0,04

pricing; the inflated cost is formed from the lack of logistics and constant demand [20]. A battery electric vehicle, in turn, is easier to maintain, since even in the absence of a developed infrastructure of charging stations, it is still possible to charge the car using public power networks.

CONCLUSIONS

Based on the above, both types of electric vehicles have their own advantages.

A hydrogen fuel cell electric vehicle is superior to a battery electric vehicle as for several factors:

– *Refuelling (charging) time*. The hydrogen refuelling time is comparable to the refuelling time of a conventional car with an internal combustion engine, in contrast to a BEV, where this interval can reach 12 hours with low charger power.

– *Safety*. Safety is defined by the chemical properties of hydrogen; its mass is 14,5 times lighter than air, as a result its diffusion properties are 14,5 times higher, which allows it to be quickly removed from a leaky room or tank without accumulating.

– *Environmental friendliness*. The carbon footprint of the use of hydrogen EV is almost two times lower under Russian operating conditions. Also, when producing hydrogen by electrolysis of water, the carbon footprint will tend to zero.

– *No need for additional heaters*. The efficiency of a hydrogen electric vehicle is 55–60 %; due to the reaction of hydrogen with oxygen, a large amount of heat is released that can heat the car without spending additional energy. In Russian operating conditions, this is a significant advantage, since when using a battery-electric vehicle in the cold season, its power reserve is reduced almost by half.

Besides, it is worth listing the disadvantages of a hydrogen electric vehicle and possible ways to solve them:

– *Lack of infrastructure for hydrogen transport*. However, the most cost-effective way to transport hydrogen is through pipelines. Currently, the pipeline is free from the phenomenon of hydrogen embrittlement, which makes it possible to easily transport hydrogen using this method.

– *Environmental friendliness*. Currently, 95 % of hydrogen is produced from fossil materials. The solution to this problem comes down to solving the problem of reducing the cost of production and popularising green hydrogen for road transport.

The operating efficiency of electric vehicles is largely determined by the area of operation. Based on the calculations carried out, it was established that in the Russian Federation, an electric vehicle powered by a hydrogen fuel cell has an advantage over a battery-powered one. This is largely due to the method of electricity production, where more than 60 % comes from combustion of hydrocarbons. The main disadvantage of a hydrogen electric vehicle is the lack of a wider network of hydrogen fuelling stations. The lack of necessary infrastructure leads to a significant increase in the cost of hydrogen and, consequently, in the cost of the operation of vehicles.

To summarize, the electric vehicle is only a tool with high potential, which is due to its indirect impact on the environment during manufacture of the vehicle itself and while producing fuel, therefore, generation of electricity or production of hydrogen in a non-polluting method will increase decarbonisation of road transport.

Table 2

Fuel-related operation costs for a battery electric vehicle and for a hydrogen electrochemical vehicle [performed by the authors]

Power plant type	Electric vehicle mileage, thousand km					
	50		100		200	
	Battery		Battery		Battery	
Fuel expenses, thousand rubles	26,8	125	53,7	250	107,4	500

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