Chapter

Sustainability Analyses for Hydrogen Fuel Cell Electric Vehicles

Hüseyin Turan Arat, Bahattin Tanç and Nevzat Özaslan

Abstract

One of the most important energy sources for well and availability is undoubtedly hydrogen. Both the production capacity and the usability of hydrogen in various industrial sections are continuing to increase significantly and sustainable. With this high trend, it is unthinkable that hydrogen is not a part of the automotive industry. The aim of this book chapter is giving info on the hydrogen fuel cell electric vehicles potential which have developing e-motor, charging capabilities and battery capacities; and illustrate the upgrade their stars on industry. Basic fundamentals, structural features, merits & demerits and energy efficiency analyzes will be done. In addition, for the future of sustainable mobility, the future milestones will be discussed and the current economical manner will be discussed in terms of life cycle assessment and environmental perspective. As a result, a comprehensible hydrogen fuel cell electric vehicle potential will be examined in both the automotive industry and all stakeholders. FCEVs on availability of autonomous vehicles will also be discussed, too.

Keywords: sustainability analyses, fuel cell electric vehicle, life cycle assessment, energy analyses

1. Introduction

Humanity has tended to supply energy from fossil fuels since the industrial revolution. Although this trend has paved the way for great advances in the name of humanity and has provided the necessary energy needs, new searches have been taken due to the limited availability of fossil fuels and the regular increase in human energy needs. As a result of these efforts, alternative energy has become the most important resource in terms of sustainability by being more environmentally friendly and renewable than fossil fuels. Considering the harm that fossil fuels cause to the environment due to carbon emissions, electric vehicles and hydrogen fuel cells have also come to the fore as environmental sustainability with zero emission values. The OECD announced that the health expenditure resulting from air pollution caused by vehicles was approximately 550 T euro [1]. For 2018 alone, total carbon emissions were 954,677 million tons [2]. The carbon emission, which was previously at the level of billion tons, has shown a downward trend in recent years with the introduction of alternative energy sources. In this regard, states have ended the policy of obtaining fossil fuel from alternative energy sources which are completely environmentalist.

The European Union has adopted the policy of reducing GHG by 40% by 2030 and by 80% by 2050 [1]. As a result of this policy, the European Union states have decided to support the infrastructure of electric vehicles and hydrogen fuel cells in order to reduce carbon emissions in their own countries. Germany, one of the most important examples of this, has commissioned 34 hydrogen refueling stations so far and aims to increase this number to 400 by 2023 [3]. According to the research conducted by Mckinsey company, it is stated that an investment cost of approximately 3 Billion € is required for 1 M hydrogen fuel cell vehicle [3]. Asian states have also added to their policies the support of hydrogen fuel cell vehicles to solve the GHG problem. The Japanese government, 320 hydrogen filling plant to put into operation by 2025 and 800,000 vehicles on the road aims to remove by to 2030.

Due to the goal of reducing carbon emissions, the most important alternative fuel is the hydrogen which obtained from renewable energy sources. The idea of using hydrogen as a fuel is not a new idea but new technologies have enabled hydrogen to be sustainable. In order to use hydrogen, which is present as compounds in nature, it needs to be purified. The energy sources of the methods used to purify hydrogen should also be examined. Because if these methods use an energy source that leaves a carbon footprint, the hydrogen produced by this method cannot be considered as an alternative energy source. There are two types of hydrogen purification processes that are actively used. These are obtained from methane in natural gas and electrolysis, a method of obtaining from water [4].

Nowadays, hydrogen, which will be used as a clean alternative fuel, should be purified by electrolysis. The electricity used in the electrolysis method should also be provided from renewable energy sources. Otherwise, the GHG emission will be higher than for internal combustion engines [4]. The technologies of hydrogen fuel cell vehicles have not reached maturity yet, but electric vehicles, the most powerful alternative, have reached maturity. Even though electric vehicles have reached maturity, there are a few issues where hydrogen fuel cell vehicles are still superior, and they still make hydrogen-fuel cell vehicles the best alternative. The major advantage of hydrogen fuel cell vehicles over electric vehicles is that they offer a range as long as internal combustion engines. Hydrogen fuel cell vehicles also have the advantage of filling as soon as internal combustion engines. In order to increase the market share of hydrogen fuel cell vehicles, manufacturers expect the demand to be created and the infrastructure to be strengthened, while consumers want the vehicles to be produced, parts supply shortage and infrastructure to be improved. States, on the other hand, have accelerated the infrastructure studies to break this paradox. In this way, producers will start production as infrastructure is waiting without demand, and consumers will start to buy cars through government investments.

Even though hydrogen refueling stations are the first investment that comes to mind, and can listed the most important investments of state and private companies as water, using renewable energy (wind, solar, wave energy) by electrolysis method and laying pipes for the transportation of hydrogen. Other advantages of hydrogen fuel cell vehicles compared to vehicles using an internal combustion engine are that they are vibration free, do not require shifting and are quiet, while the cons can be considered to waive the luggage volume for the tanks to be loaded with hydrogen [5]. The current production costs of hydrogen fuel cell vehicles are still higher, as compared to electric vehicles, because their technology does not reach maturity [5]. The Toyota Mirai reached a 500 km range with a 1.6 kW engine and a high pressure 5 kg hydrogen tank [6]. The current price of hydrogen ranges from $ 12.85 to $ 16. On average, the price of hydrogen per kg is $ 13.99 [7]. This price is expected to drop to at least $ 4 per kilo with the maturation of electrolysis technology [8]. Hydrogen gas is not more dangerous than other fuels. Naturally, all fuels must be flammable and hydrogen is a flammable fuel too. Hydrogen was also used as city gas before natural gas came to USA [9]. One of the less dangerous of hydrogen can be expressed with its less density. In this way, in case of any leakage, it will increase in the atmosphere since the hydrogen density is low [9].

In spite of this critical info about hydrogen, fuel cells and vehicles; a foresight future of hydrogen and related items has been published as a report [7] by International Energy Agency, right now. A critical future perspective is observed very detailed on hydrogen for G20 meeting. All fields of hydrogen were summarized and enlighten descriptions were given for future aspects and sustainability of hydrogen in terms of industrial applications and transportation sector.

In this book chapter, authors aim to given the fundamentals of fuel cell vehicles in addition with sustainably manner. Also, an example of fuel cell vehicle energy performance was illustrated with AVL Cruise, too. And lastly important future recommendations were mentioned.

2. Fuel cells and vehicle applications

Energy is the wanted key component in all industrial applications for everyone. In case of sustainability, one of the most important necessities is energy source. In terms of source, hydrogen is the one of the most abundant energy carrier in the world. Addition of this importance, fully environmental friendly structure of hydrogen that it is becoming with its nature, prefers as a carbon free source, too.

Basically, fuel cell can be expressed as; electrochemical device which converts the chemical energy to electric energy by using different fuels. There are six well known fuel cells and named as Polymer Electrolyte Membrane (PEM), Alkaline (AFC), Phosphoric Acid (PAFC), Solid Oxide (SOFC) and Molten Carbonate (MCFC). The main differences of each other are operating temperatures and electrodes. In authors previous study [10] a detailed illustration of fuel cells was shown and refigured in **Figure 1**.

In transportation sector, generally PEM type fuel cell is preferred. The main reason of this selection is depended on the operation temperature. Usually, fuel cell vehicles driven with PEM cells. Various automotive manufactures on fuel cell

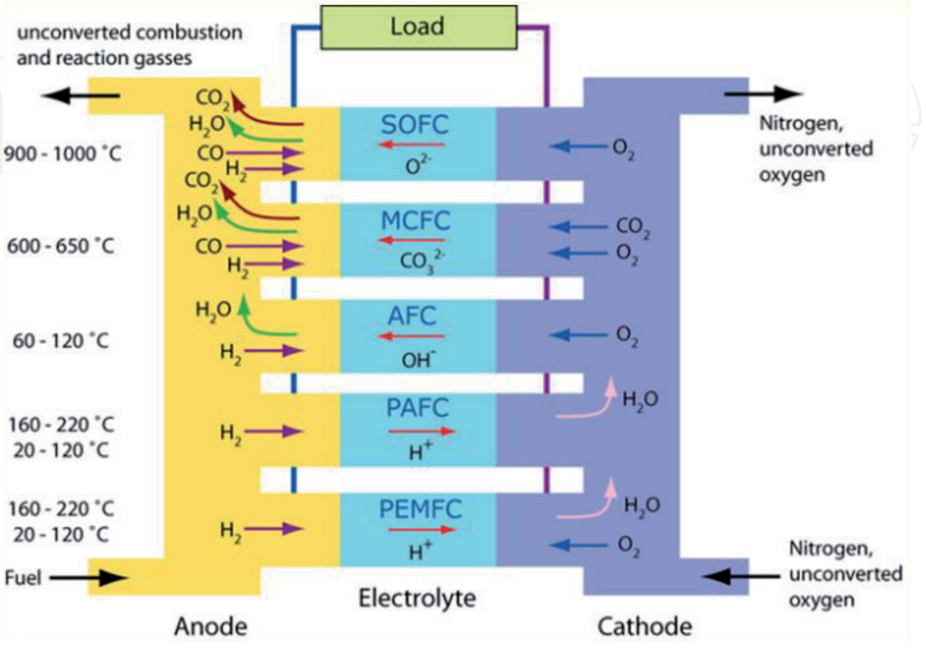

Figure 1.
Fuel cells structures and operation temperatures [10, 11].

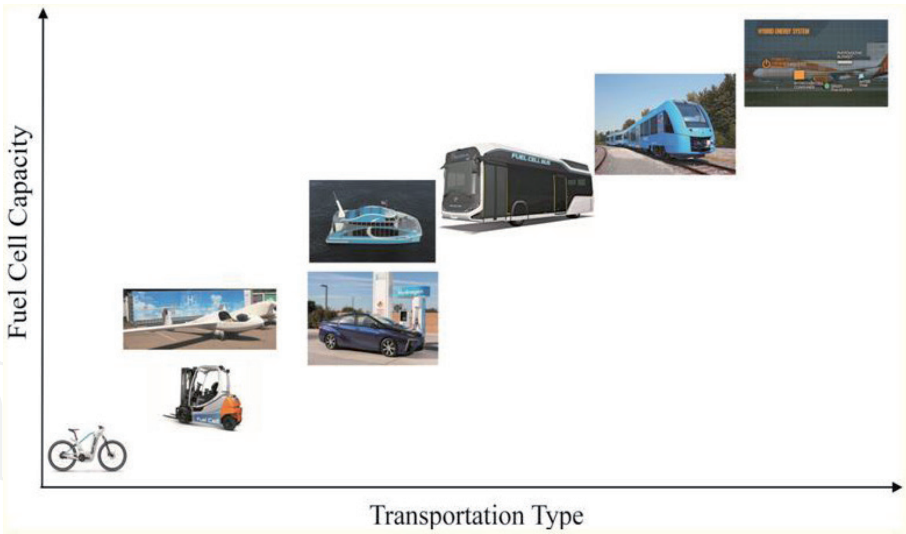

Figure 2.
Fuel cells in transportation industry.

vehicle (Toyota, Hyundai, Honda, and Mercedes [on production not concepts]) tended to use PEM with 45–60% efficiencies.

On the other hand, not only automotive sector but also all fields of transportation industry, given importance on fuel cells. **Figure 2** illustrated the sample products of transportation industries which includes land, marine and air vehicles.

In addition to all these, especially in the technological development process, the studies carried out in fuel cells have increased importance in recent years. Especially in Europe, important moves are made on fuel cell propulsion in marine and train transport and its infrastructure is created for them. On the other hand, large aviation companies are working on driving aviation with electricity and fuel cell. At this point, PEM fuel cells appear to be the most suitable way in terms of operating parameters. Since such fuel cells use hydrogen as fuel; all governments interested in the subject that are preparing and investing in hydrogen refueling stations. As such, fuel cell related sectors will emerge as rising stars in the next 20 years.

3. Sustainability analyses

Sustainability is one of the most important analyzes for each manufactured production and developed systematic. For all theories, the definition and analysis of sustainability consists of three basic perceptions: Environmental, Economic and Social factors. Hydrogen energy sustainability assessments generally give positive results in all three perceptions.

In environmental manner; life-cycle analysis, material flows, resource accounting and ecological footprint headings can be listed and should analyzed. For hydrogen powered fuel cell vehicles, Life Cycle Assessment (LCA) analyses were detailed analyzed by [12–14].

In terms of economic analyses of sustainability; cost/benefit analysis, modeling, regressions and scenarios were done by various researchers for fuel cell vehicles. General opinion of these studies summarized as, the costs of fuel cell vehicles with indeed materials were expensive nowadays but in the short run, combined with newly produced materials and increased efficiency, hydrogen supply–demand balance in transportation sector would change positively, prices will decrease and demand will increase.

When it comes to social effects, it is seen that, social effect is in a much better state than other effects. In particular, the fact that mass production FCEVs take

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place in the transportation sector and improves sales figures multiply every year; the social perspective of people perceived positively. In the surveys, the majority of the subjects stated that they could buy fuel cell vehicles in the near future. In addition, governments, especially Japan, have started to organize their own programs on the usage of hydrogen energy and set up departments on energy ministries. The G-20 summit (2019) is an important touchstone for this issue.

In addition, almost all well-known car manufacturers produce their concept fuel cell vehicles. In this case, it significantly strengthens social sustainability. This book chapters references were prepared for readers to gaining more information of this critical issue [1–50].

Considering environmental, technological and social factors; the sustainability of fuel cell electric vehicles will gradually increase its importance over the next 20–30 years. Parameters such as increasing population, decreasing energy sources, carbon foot-print minimization, consumer demand, the evolution of technology into electrical propulsion systems, etc. are clues that the sustainability of FCEVs will be continue.

4. A simulational example of fuel cell vehicle performance analysis

In this section, an example of the simulation stages and results of fuel cell electric vehicle modeled with AVL-Cruise simulation program were given. The AVL (Anstalt für Verbrennungskraftmaschinen List) company, founded in 1948 by Professor Hans LIST in Austria, has become one of the world's leading engineering simulation, measurement, application, modeling and realization companies [15]. One of the main simulation tools is AVL-Cruise. With this program the performance, emission and energy distribution results of any conventional, hybrid, fuel cell and electric vehicle can be concluded with different simulation and code software integrations (Matlab/Simulink, C ++, etc.).

Figure 3 shows the simulation interface of an exemplary fuel cell electric vehicle in AVL Cruise. From the modules bank, it can be chosen from a wide variable options, including all mechanical devices and interactive program options, fuel cell, electric motors, main power units, power train and gearbox, driving cycles, cockpit and driver details.

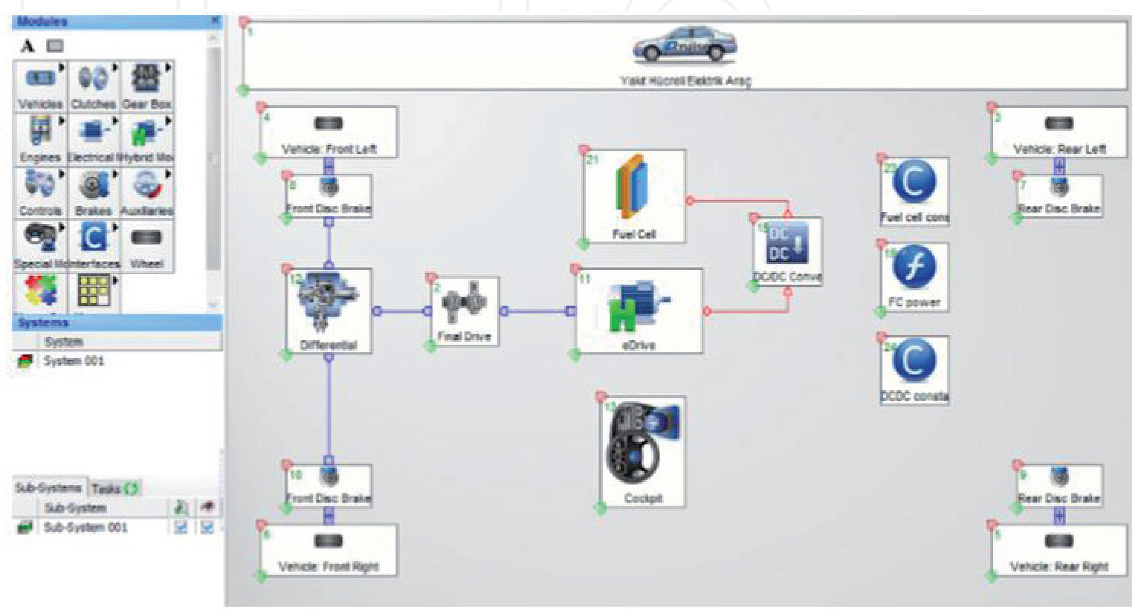

Figure 3.
Example of AVL schematic [15].

The components selected from the module pool must be inter-connected each other. In **Figure 3**, the connection system was shown and colors indicated as blue: mechanical, red: electronic colors should be connected as shown in **Figure 4**.

All simulation programs have specific operating systems. In the system where codes and certain mathematical calculations [15] will be performed, the input conditions must be determined and entered as data. In order to give accurate approximate results for the program, some of the required vehicle specifications entered the program must have been previously measured (tested) or either measured data from the manufacturer (factory data). After obtaining the accuracy report in the system, it can proceed to the simulation execution section shown in **Figure 5**. An important point is noted here, that the vehicle, the driving cycle and the cockpit and the driver's part must be specified in the project sub-stage.

When the results section is started, the main reporting results and the input data given according to different parameters and the simulated results are displayed in the tree image. For example, **Figure 6** shows instant energy input/output diagram (Sankey). As shown in the sections indicated by red letters in the figure; (a) result tree

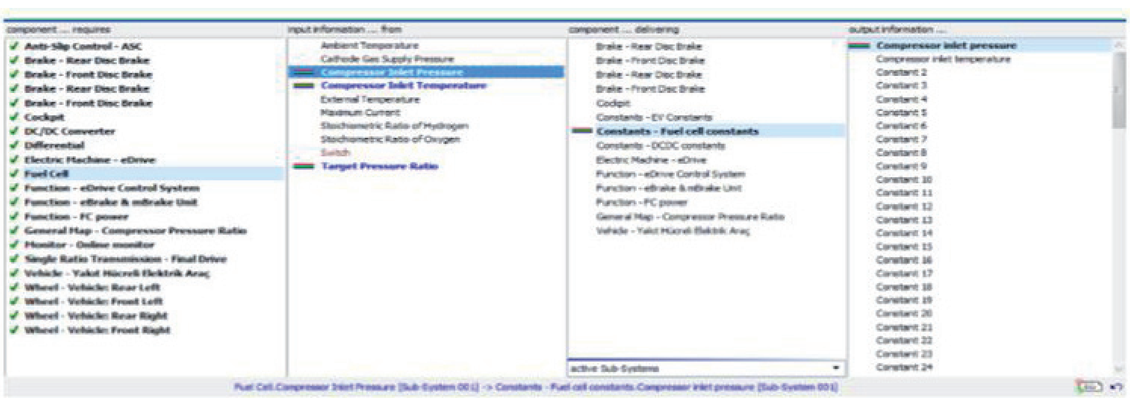

Figure 4.
Connection and communication units page example [15].

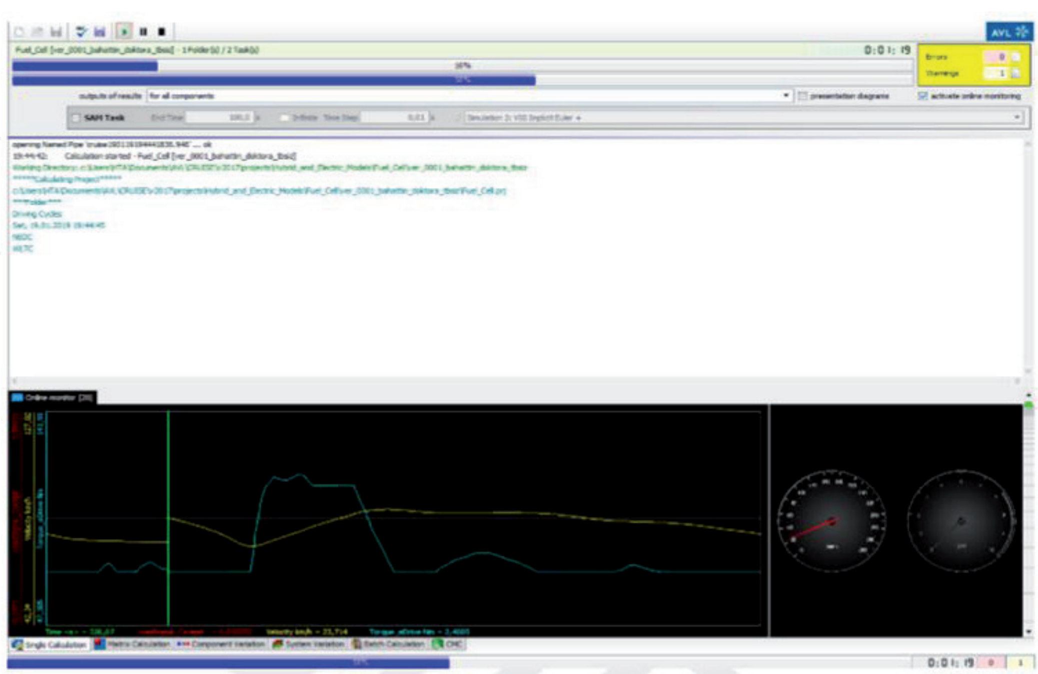

Figure 5.
Single computational analysis screenshot [15].

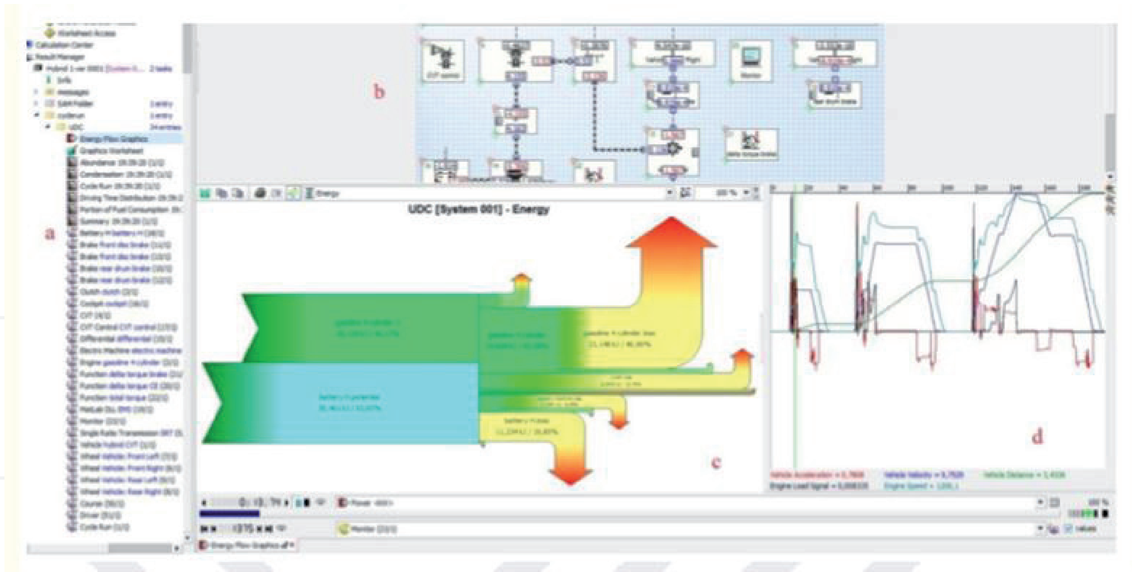

Figure 6.
Example model Sankey diagram result example of the vehicle [15].

chart; (b) instant power exchange on the vehicle; (c) Sankey diagram; and (d) the chart in where the instant results can be seen according to the selected driving cycle.

5. Conclusion

In this book chapter, authors tented to give the last critical info's about; the fundamentals of the development of hydrogen energy, the necessity of producing with renewable energy instead of fossil fuels, the importance of reducing the carbon foot print for emissions, the reasons for governments to consider hydrogen as an alternative fuel, the required steps had been taken, and the investments should be taken into consideration.

The usage of hydrogen in fuel cell vehicles and their applications on various transportation sectors were explained. The sustainability of hydrogen fuel cell vehicles mentioned detailed with newest literature and reported studies.

An essential example of energy distribution and efficiency analyses were consisted for a modeled hydrogen fuel cell vehicle which were made by using AVL Cruise program.

In the future perspective, either with mentioned references of this book chapter is expected that, the potential of hydrogen in the transport sector will increase its potential and the cost of materials would decrease. In this way, it is envisaged that the range will be comparable with internal combustion engines and carbon emissions with electric vehicles.

As an important result of fuel cell vehicles phenomenon; it will play an important role in autonomous vehicle sector, too.

6. Future recommendations

Fuel cell electric vehicles will be a crucial milestone in the future in line with the sustainability of the Earth's environmental ecosystem and therefore the decisions of many countries' governments. Developments in the economic sustainability of fuel cell vehicles are also expected to rise in parallel with this situation.

Reducing costs in hydrogen production methods, establishing a large network of Hydrogen Refueling Station and increasing fuel cell efficiency are among the main objectives of researchers. Considering that energy, environment and economy are the main factors of sustainability, diversity in fuel cell membranes, reduction of emission gases and reduction of preliminary costs are possible in the next quarter century.

The main materials such as membranes, plates and electrolytes will be the most appropriate study subjects for the future fuel cell systems. And then, to ensure sustainability aspects; the efficiency, cost, environmental effects and social manners will follows the materials studies. The last but not the least, the economy of hydrogen enlightened the visionary perspective for future sustainable alternative energy. For this reason, the authors strongly recommend that everyone work selflessly to give the necessary importance for hydrogen in all over the world.

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Conflict of interest

The authors declare no conflict of interest.

Nomenclature

AVL	Anstalt für Verbrennungskraftmaschinen List
AFC	Alkaline Fuel Cell
FCEV	Fuel Cell Electric Vehicle
GHG	Greenhouse Gases
IEA	International Energy Agency
LCA	Life Cycle Assessments
MCFC	Molten Carbonate Fuel cell
OECD	Organization for Economic Co-operation and Development
PAFC	Phosphoric Acid Fuel Cell
PEM	Polymer Electrolyte Membrane (Fuel Cell)
SOFC	Solid Oxide Fuel Cell

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