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DEPARTMENT OF MECHATRONICS AND ROBOTICS

MEC104 2020-2021

Hydrogen fuel cell vehicle

Sustainable Development Assignment

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1. Product or Process Selected

As a result of the widespread use of automobiles, fossil fuels are becoming less and less non-renewable. And car emissions exceed the standard, putting enormous pressure on the environment, leading to global warming, sea level rise. In recent years, China has emphasized the need for sustainable development, and fuel vehicles are obviously contrary to national conditions. Therefore, in order to protect the environment, no longer overexploit non-renewable resources, more people's health, we should strive to study and promote new energy vehicles.
Pure electric vehicles are essentially powered by thermal, hydropower, nuclear and wind power, while China accounts for 74% of thermal power generation as of July 2018. Therefore, pure electric vehicles are not environmentally friendly.
In contrast, hydrogen fuel for hydrogen fuel cell vehicles is a renewable resource that produces electrical energy and harmless water vapor by-products after an electrochemical reaction, and is therefore accepted.
Therefore, I decided to choose hydrogen fuel cell vehicles as my research topic.

2. Outline of the scope of product or process

In this section, three aspects will be covered: design features, market situations, and general sustainable issues.
In the first aspect, the most central part of a hydrogen fuel cell car, the hydrogen storage tank, will be introduced at first. Secondly, the working principle of hydrogen fuel cell will be introduced. Finally, the composition and working principle of hydrogen fuel cell vehicles are introduced.
In the second aspect, the market will be analyzed from the market share of existing fuel vehicles and hydrogen fuel cell vehicles.
In the third aspect, the sustainable issues of the hydrogen fuel cell vehicles will be analyzed from economic, environmental and social aspects.

2.1 Design features:

2.1.1 Hydrogen storage tank:

Hydrogen energy fuel cell vehicles have many component systems, of which hydrogen storage system is one of the core systems of hydrogen energy battery vehicles. In order to ensure that hydrogen energy vehicles have a range greater than 500km, the hydrogen storage system must carry at least 5kg of hydrogen, but due to the low volume of hydrogen storage density of high-pressure hydrogen storage tanks, resulting in a large volume of hydrogen storage system, which is very detrimental to the structural design and optimization of the car. Thanks to the development of automotive high-pressure hydrogen storage tanks, today's new carbon fiber winding aluminum inner bile high-pressure hydrogen storage tanks not only have large volume, light quality, but also can withstand greater pressure.

Compressed hydrogen storage systems have been proven in hundreds of prototype fuel cell vehicles and can be commercially used in small-volume production [1]. Although physical storage has not yet met all of the U.S. Department of Energy's (DOE) automotive storage targets, many have been met and only a few key areas require further improvement, including weight density, volume density, and cost.

The table at the bottom of the page is the U.S. Department of Energy's status and objectives for the weight density, volume density, and cost of in-vehicle compressed hydrogen storage systems [1].

TABLE 1. Projected Performance and Cost of Compressed Automotive Hydrogen Storage Systems Compared to 2020 and Ultimate DOE Targets[a]

Storage System Targets	**Gravimetric Density** kWh/kg system (kg H_2/ kg system)	**Volumetric Density** kWh/L system (kg H_2/L system)	**Cost** \$/kWh (\$/kg H_2)
2020	1.5 (0.045)	1.0 (0.030)	\$10 (\$333)
Ultimate	2.2 (0.065)	1.7 (0.050)	\$8 (\$266)
Current Status (from Argonne National Laboratory)	**Gravimetric Density** kWh/kg system (kg H_2/ kg system)	**Volumetric Density** kWh/L system (kg H_2/L system)	**Cost[b]** \$/kWh (\$/kg H_2)
700 bar compressed (Type IV, single tank)	1.4 (0.042)	0.8 (0.024)	\$15[c] (\$500)

a Assumes a storage capacity of 5.6 kg of usable hydrogen.
b Cost projections are estimated at 500,000 units per year and are reported in 2007\$.
c Cost projection from Strategic Analysis (November 2015).

According to the goal, the on-board hydrogen storage system will complete improvements in all aspects of weight, capacity, and cost, making it a suitable source of power for hydrogen fuel cell vehicles.

2.1.2 The working principle of a hydrogen fuel cell:

Hydrogen ions flow through the catalyst, separating its electrons. Then, the electrons flow along the wire from positive to negative, generating usable electrical energy, while the remaining hydrogen

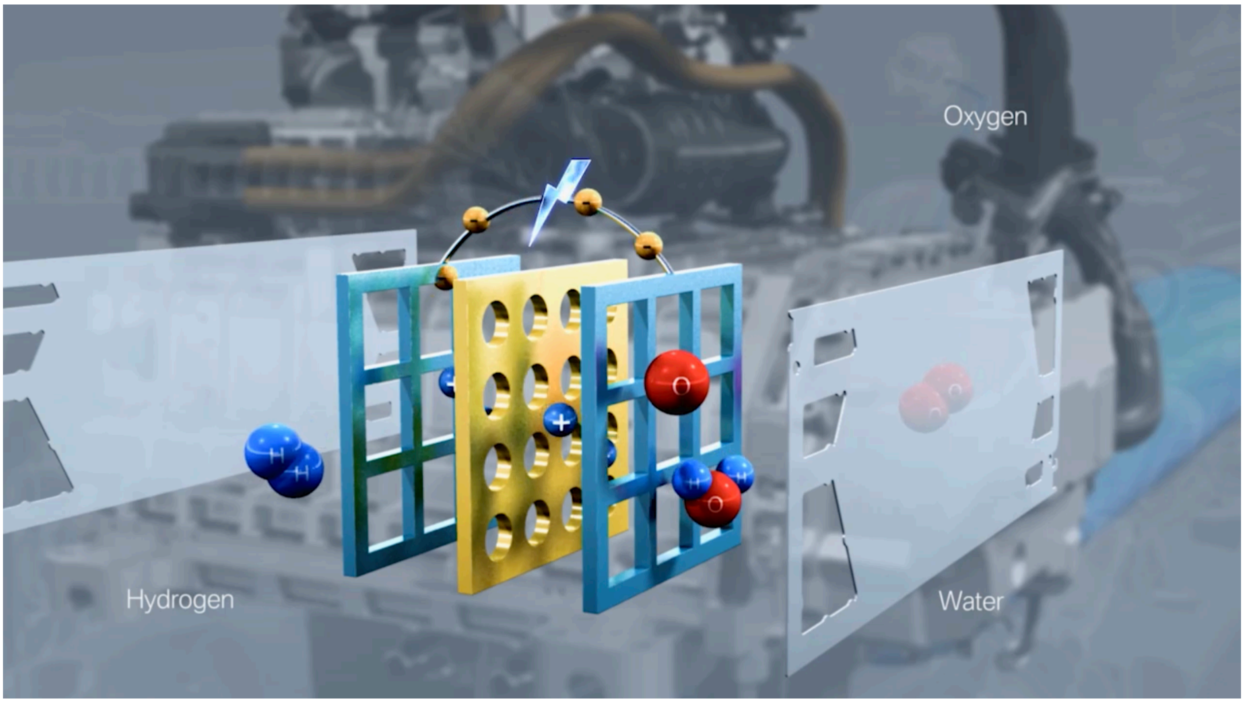

Fig. 1. The working principle of hydrogen fuel cell [3]

ions pass through the membrane and recombine on the other side, combining with oxygen to form water. The electricity generated by the electrons passes through the conductor and generates on-demand current when pressing the accelerator, thereby providing various powers required by the driver [2].

The schematic diagram of this process is shown in the figure above.

2.1.3 The composition and working principle of hydrogen fuel cell vehicles:

Hydrogen fuel cell vehicles are driven by electric motors, so they are classified as electric vehicles. The common abbreviation is FCEV, abbreviated as "fuel cell electric vehicle", which is in sharp contrast to "battery electric vehicle".

The energy supply system of hydrogen fuel cell vehicles consists of hydrogen storage tanks, fuel cells, and Peak Power Battery.

There is a key difference between hydrogen fuel cell vehicles and other electric vehicles, that is, hydrogen vehicles use fuel cells to generate electricity. This is different from an all-electric car, which does not get power from a built-in battery.

The electricity generated by the hydrogen fuel cell can take two paths, one is to flow to the motor and directly supply power to the FCEV, and the other is to charge the battery, which stores energy until the engine needs it. This battery is much smaller than the battery of an all-electric car, and therefore lighter, because it is constantly charged by the fuel cell [3].

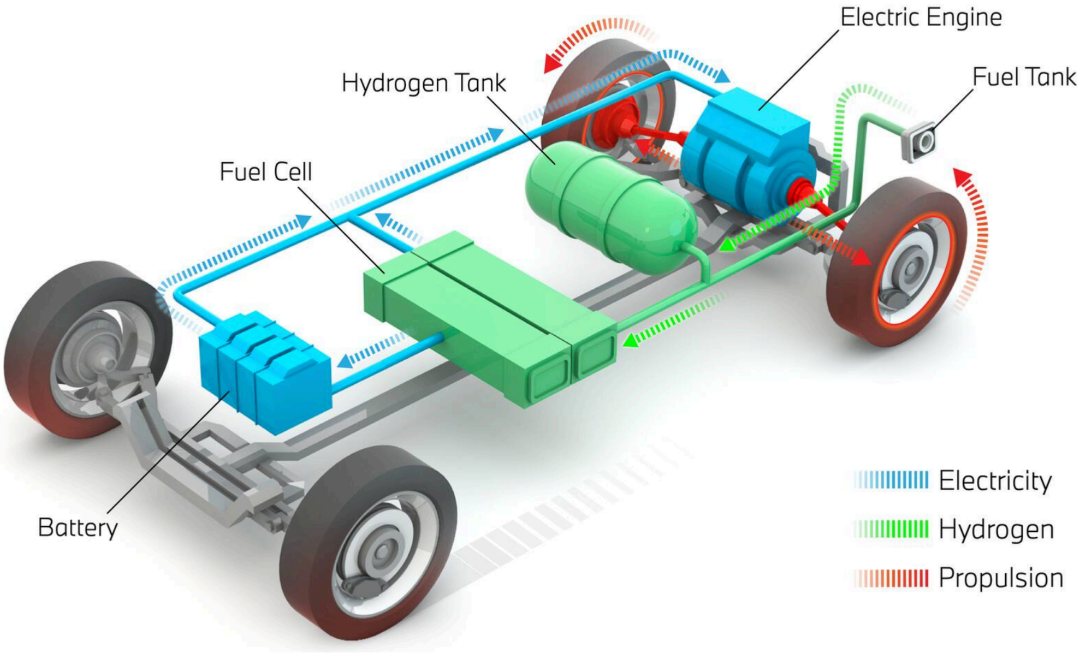

Fig. 2. The working principle of hydrogen fuel cell vehicles [3].

2.2 Market situations:

Currently, fuel vehicles occupy a certain market in almost the world. However, commercial hydrogen fuel cell vehicles are only used in California, and a small number of buses using hydrogen fuel cells are being tried on a small scale in China, Japan and other places. Therefore, the future market of hydrogen fuel cell vehicles is very broad, and it is expected to gradually replace some traditional fuel vehicles or pure electric vehicles in the world.

2.3 General sustainable issues：

2.3.1 Economic sustainability:

The purchase cost of hydrogen fuel cell vehicles is relatively high. Among the few models of fuel cell vehicles already on the market, the price of mid-to-high-end or mid-to-high-end vehicles is about US$80,000. This is almost a fully electric or hybrid car

Twice. The main reason is that the current production has not yet been large-scale industrialized mass production, and there is a high price of precious metals such as platinum used as a catalyst in the power generation process.

At the same time, as the fuel for hydrogen fuel cell vehicles, hydrogen costs about US$14 per pound (0.45 kg) in the United States and US$4.80 per pound in Germany. Moreover, 1 pound (0.45 kg) of hydrogen can enable FCEV to drive approximately 28 miles (45 kilometers) [3].

Therefore, the current cost of running a hydrogen car per mile is almost twice that of a domestic rechargeable battery-powered car.

Such high purchase costs and operating costs make the market share of hydrogen fuel cell vehicles small, but through the gradual maturity of technology to achieve mass production, Rücker believes that the final cost will be close to that of pure electric vehicles, thereby gaining a larger market share [3].

2.3.2 Environmental sustainability:

Fuel cell electric vehicles emit only water vapor and warm air, and do not emit harmful gases.

The Argonne National Laboratory (ANL) report "Fuel Selection for Fuel Cell Vehicles: Wheel-to-Wheel Energy and Emission Effects" analyzed the greenhouse gas (GHG) emissions of the 10 most common hydrogen production and distribution pathways. ANL found that in most cases, gaseous hydrogen produces less GHG than liquid hydrogen. ANL also studied the impact of hydrogen on the use of petroleum and found that using hydrogen as a fuel would reduce petroleum use by nearly 100%.

The figure below shows the percentage change of greenhouse gas emissions in the production of 10 kinds of hydrogen [4].

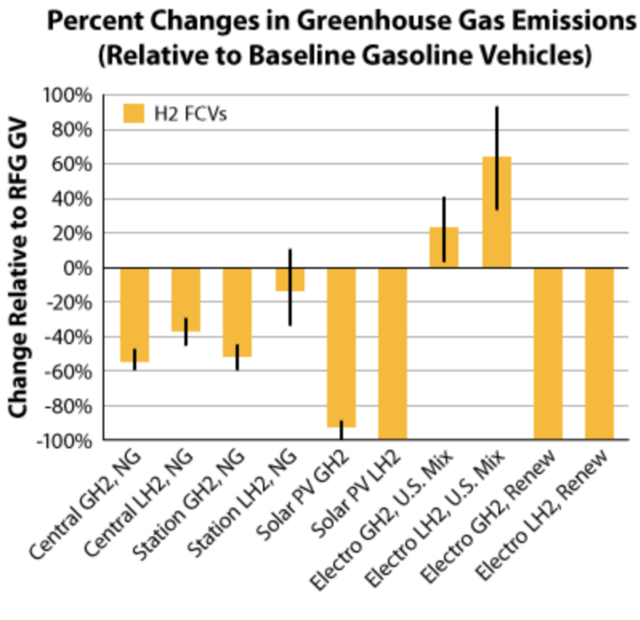

Fig. 3. Changes in the percentage of greenhouse gas emissions in the production of 10 types of hydrogen

Therefore, in the sustainable development of the environment, hydrogen fuel cell vehicles have great advantages, which can not only efficiently use resources, but also reduce or even eliminate environmental pollution.

2.3.3 Social sustainability:

The current policies of various countries tend to reduce fuel vehicles and increase new energy vehicles. In 2015, the US Congress increased the fuel cell vehicle tax credit to US$8,000. The Central Government of Japan and the Tokyo Metropolitan Government will also subsidize 2 million yen (approximately US$15,884) and 1 million yen (approximately US$7942) to buyers of fuel cell vehicles in Tokyo [5]. So from a social perspective, hydrogen fuel cell vehicles will be vigorously promoted by the government. At the same time, the general public's acceptance of this new energy vehicle is gradually increasing, and more and more people are willing to spend more money to buy environmentally friendly products.

3. Framing of Product or System in a Sustainable Development Context

3.1 Government:

In terms of fuel cell commercial vehicles, some Chinese auto companies have now entered the mass production stage. Under the continuous promotion of relevant national policies and industries, China’s fuel cell commercial vehicles will enter the regional maturity stage in 2020-2025, and will enter the outbreak in 2025-2030. Growth stage. In terms of fuel cell passenger vehicles, it is expected that the mass production stage will be entered from 2020-2025. It is estimated that China's fuel cell commercial vehicle production will reach 30,000 in 2025, and it will enter the stage of large-scale development after 2025 [5].

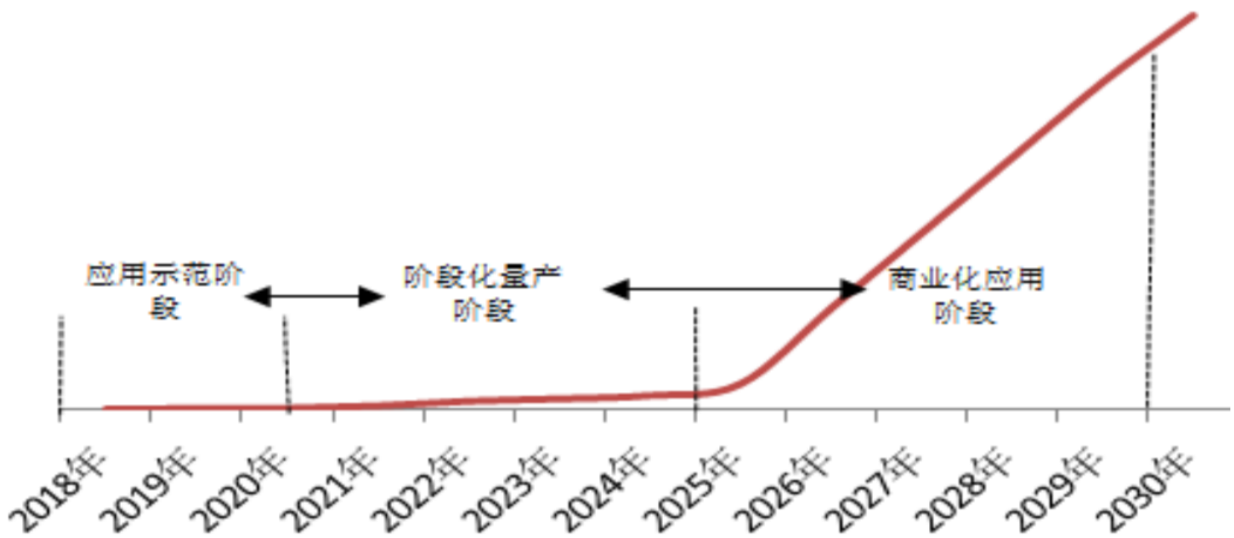

Fig. 4. 2018-1030 China's fuel cell passenger vehicle sales forecast [5]

3.2 Enterprise:

In 2009, Nissan initiated a new FCV plan in Japan. After that, in October, Nissan, Ford Motor, General Motors, Hyundai, Toyota, Daimler, Renault, and Kia Motors issued a joint statement that they will develop fuel cell vehicles. It is expected in 2015. carry out. In 2011, Hyundai Group announced its fuel cell electric vehicle (FCEV).

As shown in the table below, companies around the world have begun to participate in the R&D, production and sales of hydrogen fuel cell vehicles [6].

TABLE 2. Recent Fuel Cell Passenger Vehicle application status worldwide

	China	Japan	Europe	US
Typical 2015 available	- plugin hybrid FC version of Roewe 950	– Toyota Mirai	– Toyota Mirai	– Toyota Mirai
	– Grove (China's first fuel-cell passenger vehicle in 2019)	– Honda Clarity (leased only)	– Honda Clarity (leased only)	– Honda Clarity (leased only)
			– Hyundai Tucson	– Hyundai Tucson
			– Hyundai Nexo	– Hyundai Nexo
Image/Report Status	– In 2018, no sales of fuel-cell passenger vehicles	– 575 and 766 Toyota Mirai were sold in Japan in 2017 and 2018 respectively	– 132 and 160 Toyota Mirai were sold in Europe in 2017 and 2018	– 1700 and 1838 Toyota Mirai was sold in 2017 and 2018 respectively

	China	Japan	Europe	US
	– 50 plug-in hybrid fuel cell version of Roewe 950 were used in a demonstration operation of the project and car-sharing services in Shanghai		– Clever Shuttle and BeeZero are car-sharing companies operating with 20 and 50 FCEVs	
Level of application (model Mirai and Nexo)	<100 vehicles	> 500 vehicles	100-500 vehicles	> 500 vehicles

Source: Created by authors from source [6]

3.3 Consumer:

With the government's relevant subsidy policies and the enhancement of people's environmental awareness, more and more consumers are willing to buy hydrogen fuel cell vehicles.

4. Process Flow Diagram of Life Cycle (Cradle to Grave)

Design

(1) Features: Convert hydrogen energy into electricity efficiently

(2) Components: Fuel Tank (hydrogen), Fuel Cell Stack, Battery (auxiliary), DC/DC Converter, Battery Pack.

Manufacture

- Metal, glass, Carbon fiber composite
- Platinum catalyst
- Produce parts and then assemble them

Marketing

- Money saving
- Energy efficient
- Environmentally friendly

Usage

- Uses less or even no electricity
- No harmful gas emissions
- Replenishing hydrogen faster than charging

Disposal

- Legislation for safe disposal
- Recycling of useful components

5. Matrix of Life Cycle Stages and Sustainable Development Impacts

HYDROGEN FUEL CELL CARS **Sustainable development factor**

Life cycle stage	Depletion of reserves	Cost	Energy usage	Waste	Carbon footprint
Raw materials	Glass, metal, Platinum		Making auto parts from steel	Sand-mining (for glass)	
Manufacture		Carbon fiber composite material Expensive	Encapsulation of hydrogen, assembly of automobiles		Assembly of automobiles
Distribution	petroleum for trucks, ships etc		Transportation	Exhausts etc	Vehicle emissions
Use	Hydrogen fuel	The cost of hydrogen fuel			No
Disposal			Reuse scrap steel as raw materials		Reuse scrap steel as raw materials

Fig. 5. Sustainable development factor

6. Scoring Matrix of Sustainable Development Impacts

HYDROGEN FUEL CELL CARS **Rates of the Sustainable development factor**

Life cycle stage	Depletion of reserves	Cost	Energy usage	Waste	Carbon footprint
Raw materials	2		2	1	
Manufacture		3	4		1
Distribution	2		2	1	1
Use	1	1			-3
Disposal			1		

Fig. 6. Rates of the Sustainable development factor

7. Design Opportunities

It is recommended that the government invest more funds in the research and improvement of hydrogen fuel cell vehicles in order to be able to mass produce and reduce costs. For example, reducing the cost of hydrogen storage tanks. The specific approach can be to reduce the cost of carbon fiber composite materials or to develop lower cost alternative fiber reinforced composite materials, better use and therefore reduce the number of fiber reinforced materials contained in the storage tank.

As shown in the figure at the bottom of this page, a potential cost reduction strategy for a 700bar compression system [1].

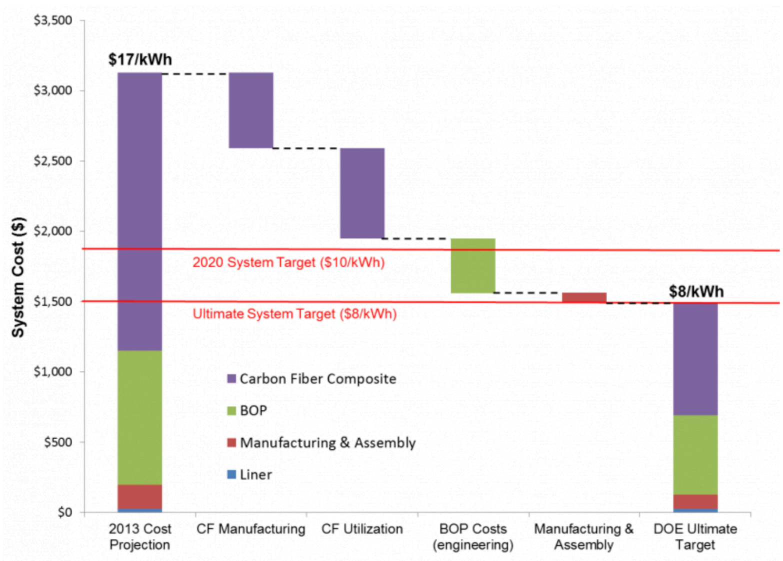

Fig. 7. Potential cost reduction strategies for hydrogen storage tanks [1]

At the same time, we should also pay attention to follow-up continuous services, such as adding hydrogen refueling stations. According to a report [6], the number of hydrogen refueling stations has increased globally from 2010 to 2019. However, in terms of total amount, it is still unable to meet the demand for hydrogen fuel cell vehicles after mass production in the future. Therefore, a large number of hydrogen refueling stations must be added.

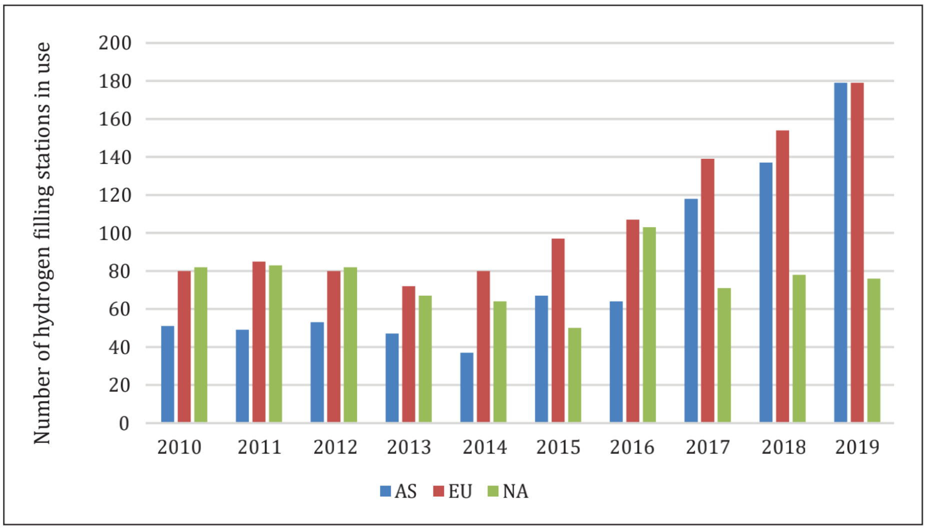

Fig. 8. Development of hydrogen filling stations by region [6]

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