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Electric Vehicle: Fuel Cells or Batteries?

Mohd Fuad bin Ibrahim[1]
Ahmad Fadzil bin Ismail[2]
Kamarul Hisyam bin Osman @ Othman[3]

[1] Department of Mechanical Engineering, Politeknik Seberang Perai, Pulau Pinang.
fuad@psp.edu.my
[2] Department of Mathematics, Science and Computer, Politeknik Seberang Perai, Pulau Pinang.
afadzil@psp.edu.my
[3] Department of Mechanical Engineering, Politeknik Seberang Perai, Pulau Pinang.
kamarul@psp.edu.my

Abstract: It will take millions of years to produce fossil fuels and existing stock is consumed relatively quick than that. Electric vehicle (EV) are the human race's best chance to replace internal combustion engines (ICE). There are two most popular technologies in EV which are battery electric vehicle (BEV) and fuel cells electric vehicle (FCEV). BEV and FCEV are basically almost the same where BEV must be charged to stored electrical power and the electrical power will run the motor. However FCEV uses hydrogen to power its electrical motor. BEV and FCEV has its own advantages and disadvantages, although BEV has slightly higher advantage edge where electrical generation to power BEV already in place compared to FCEV where we in the phase to figure it out the cheapest and the most environmentally friendly method to produce hydrogen.

Keywords: Electric Vehicle, Fuel Cells, Battery, Fossil Fuel

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1. Introduction

Fossil fuels take millions of years to produce, and existing stocks are destroyed considerably quicker than new fossil fuels are created. The fossil fuel is expected to be depleted in 2070 (Dogan & Erol, 2019). Fossil fuel also emits greenhouse gases that are threatening the environment by increasing the rate of climate change which will affect the global warming of the earth. Renewable energy is the answer to these problems. Renewable energy will not be depleted, or at least the source is too abundant, and it will not damage the environment, or the damage is very minimal.

Renewable energies are energy sources that are constantly renewed by nature and can be taken directly from the sun, indirectly from the sun, or from other natural environmental motions and systems (Ellabban et al., 2014). The example of renewable energy source is sun, wind, hydropower, geothermal, tidal, hydrogen etc.

More than half people in this world today live in urban area (Gouldson et al., 2015), logically, more CO2 emission is released to the atmosphere in the city area. One of the sources of CO2 emission are from cars. Scientist and engineers are trying to find a way to reduce or cut to zero CO2 emission from cars. One of the answers to this problem is by replacing internal combustion engine vehicle to electric vehicle (EV). EV is not just reducing CO2 emission to the environment, EV also will reduce noise contamination in urban area. This paper will explore the advantages and disadvantages of two types of EV which are EV using battery and EV using fuel cell.

2. Batteries

Tesla is a measuring unit of electromagnetic density (B) which is the basic learning concept in electrical technology. Tesla has now become the world's leading brand in producing electric car. This company was led by Elon Musk, whom the chief engineer who anchored Tesla to where it belongs now. Tesla is a non-conventional combustion engine car manufacturer that developed the electric car and released its first model named the roadster, in 2008 (Schreiber & Berge, 2018). The main reason behind the successful of electric vehicles is demand from the consumer and purchasing power to all classes of humanity. The significant increase in CO2 caused by massive fossil fuel use is now considered the main cause of rising climate change and global warming. The transportation sector that run on fossil fuels emit carbon compounds like CO2 and other hazardous emissions into the atmosphere, exposing humanity to pollution and greenhouse gas emissions.

Electric vehicles, whether pure electric or hybrid (EV/HEVs), are now becoming a reality and commercially available and have been gaining acceptance not only among environmentally conscious individuals, but also among mainstream consumers (Schreiber & Berge, 2018). There are so many factor influence in buying intention by consumer such as individual financial, performance in term of distance and range for each charging time and charging infrastructure (Thananusak et al., 2017). The factor of performance of EVs car related to the development of EVs battery. It is the core of EVs as power source and energy storage devices. The advanced and mature degree consideration in developing the EVs is the cost and endurance mileage, which is also the key to compete with traditional fuel vehicles. Therefore, it is critical to exploit the cost-effective power battery and has a crucial impact on developing the EV industry (Zhang et al., 2017).

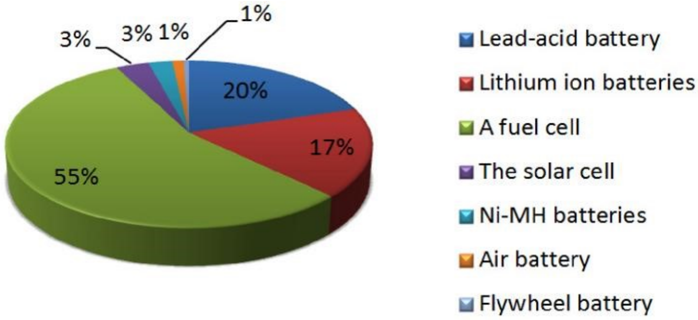


Fig. 1: Proportion of patent compared in main kinds of vehicle battery technology (Zhang et al., 2017)

Figure 1 above shows the percentage of R&D activities on EVs batteries from data on patterns in China. The main type of batteries contribute to this data is a fuel cell battery followed by lead acid batteries and lithium-ion batteries. Since the first electric vehicle was introduced in the 1890s, lead-acid batteries have been used. The batteries are inexpensive and simple to use, but they have a poor energy density (Mizuno et al., 2014). Since lead-acid batteries are too large and heavy to be used in automobiles and not practical in term of designing new car because of the space allocated for the batteries is too large to be consider, they have not gained widespread adoption or popularity beyond a few PHEVs and EVs. Construction technology evolved with the introduction of nickel metal hydride in the 90s and lithium ion began to dominate the electric car battery industry in the early 20s. Both nickel-metal hydride and lithium-ion batteries were developed with the goal of reducing size and weight, enhancing performance in terms of increasing power, recharging time, reliability, energy density and reducing the number of cells required by vehicles. Table 1 shows the comparison between types of batteries commonly used in the production of Evs car and it is clearly indicating that the advantage of using lithium ion is dominating others in term of power density, stability, good cycle life and small size with lighter weight. Based on the design of the electrode structure, lithium-ion batteries may achieve a good balance between power output and energy capacity throughout a wide variety of operating regions (Horie et al., 2007).

Table 1. Comparison of the most commonly used batteries (Sun et al., 2019)

Cathode Material	Specific Energy (Wh/kg)	Cycle	Optimal Working Temp (°C)	Efficiency (%)	Advantages	Disadvantages
Lead acid	30–50	2000–4500	−20–60	70–90	Low cost, mature technology, high specific power	Low specific energy, short service life, high maintenance requirements
Ni-Fe	30–55	1200–4000	−10–45	75	Good scope for traction applications	Low specific energy, power and energy density; high self-discharge, hydrogen evolution, high purchase and maintenance cost
Ni-Zn	60–65	100–300	−10–50	76	High specific energy	High cost, short service life
Ni-Cd	40–50	2000–3000	−40–60	60–90	High specific energy	High cost cadmium toxicity, recycling issues
Ni-MH	50–70	500–3000	−40–50	50–80	High specific energy, safety, long service life	High cost, high self-discharge, memory effect
Ni-H_2	60–70	6000–40000	−20–60	80–90	Extreme long-life cycle and tolerance to overcharge or over-discharge without damage	Expensive, low volumetric energy density, self-discharge proportional to H_2 pressure
$LiCoO_2$	150–190	500–1000	150	80–90	In common use, high power density, high energy density	Low self-discharge, low safety, high cost
$LiMn_2O_4$	100–135	500–1000	250	85	High power density, very good thermal stability	Moderate cycle life, lower energy
$LiFePO_4$	90–120	1000–2000	270	90	Very good thermal stability and cycle life, good power capability no memory effect, lighter and smaller	Low energy density
$LiNiMnCoO_2$	140–180	1000–2000	210	90–95	High power density, high energy density, high energy efficiency, good cycle life	Structural/chemical instabilities during repeated cycling

2.1 Working principle of Lithium ion EVs battery

EV battery packs are classified into three categories: cell, module, and pack. A cell is made up of a single electrochemical unit with the chemistry's lowest voltage and the unit of cells are coupled in series, parallel, or mixed configurations to form a module to provide the necessary power for the traction motor and auxiliary systems and this module pack in a container which is plastic or metal with the battery necessary management control system. (Saw et al., 2016). Battery packaging is designed in cylindrical cell, prismatic cell, and pouch cell.

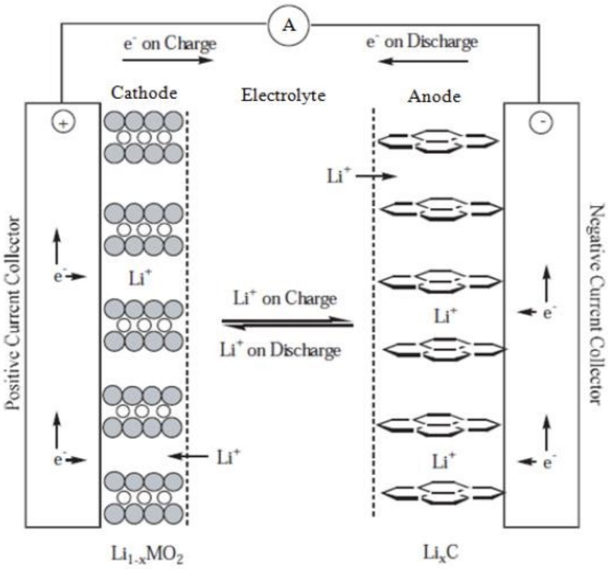
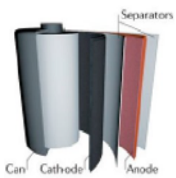
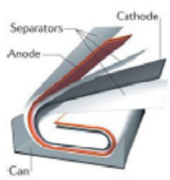
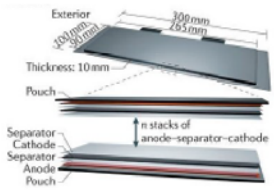


Fig. 2: Schematic of the electrochemical reactions in lithium-ion cells (Chen et al., 2012)

Cathode, anode, electrolyte, and separator are the four primary components of lithium-ion battery cells. Batteries are essentially storage media comprised of two electrodes immersed in an electrolyte. Lithium ions are electrodes that allow charge to flow. Ions pass through the electrolyte, while electrons are insulated. The anode includes a high concentration of intercalated lithium in a charged state, whereas the cathode is lithium depleted. A lithium ion leaves the anode and migrates through the electrolyte to the cathode during the discharge, while its associated electron is collected by the current collector and used to power an electric device (Daniel, 2008). Table 2 depicts those essential components with their functions and general materials and the working principle of electrochemical reactions in lithium-ion batteries. Lithium metal oxide for the cathode materials, which have either a layered or tunnelled structure on an aluminium current collector, and typically litigated graphite for the anode materials, which also have a layered structure on a copper current collector, are the electrode materials in lithium ion batteries. Lithium in the anode is ionised and released into the electrolyte during the discharge process. Lithium ions pass through a porous plastic separator before being deposited in atomic-sized pores in the lithium metal oxide cathode. This becomes an electric current traveling to an external load.

Table 2: Cell designs and Relative Strengths and Weaknesses(Miao et al., 2019)

Shape	Cylindrical	Prismatic	Pouch
Diagram			
Electrode Arrangement	Wound	Wound	Stacked
Mechanical Strength	++	+	–
Heat Management	–	+	+
Specific Energy	+	+	++
Energy Density	+	++	+

This section discusses the many types of Li ion battery packaging, including cylindrical cells with spiral wound active material, prismatic cells with elliptically wound active material, and pouch cells with stacked active material plates. For cylindrical or prismatic cell cans, aluminium and stainless steel are commonly employed. The pouch cell, on the other hand, uses soft packaging, which is typically metalized plastic (Saw et al., 2016).

3. Fuel Cells

Fuel cell technology is a viable energy replacement for internal combustion engines. Despite all the hype, fuel cell actually was discovered by William Robert Grove more than 150 years ago (Ortiz-Rivera et al., 2007). Grove found that if two platinum electrodes were arranged with one end submerged in sulphuric acid and the other ends enclosed in oxygen and hydrogen containers, an uninterrupted current would flow between these electrodes.

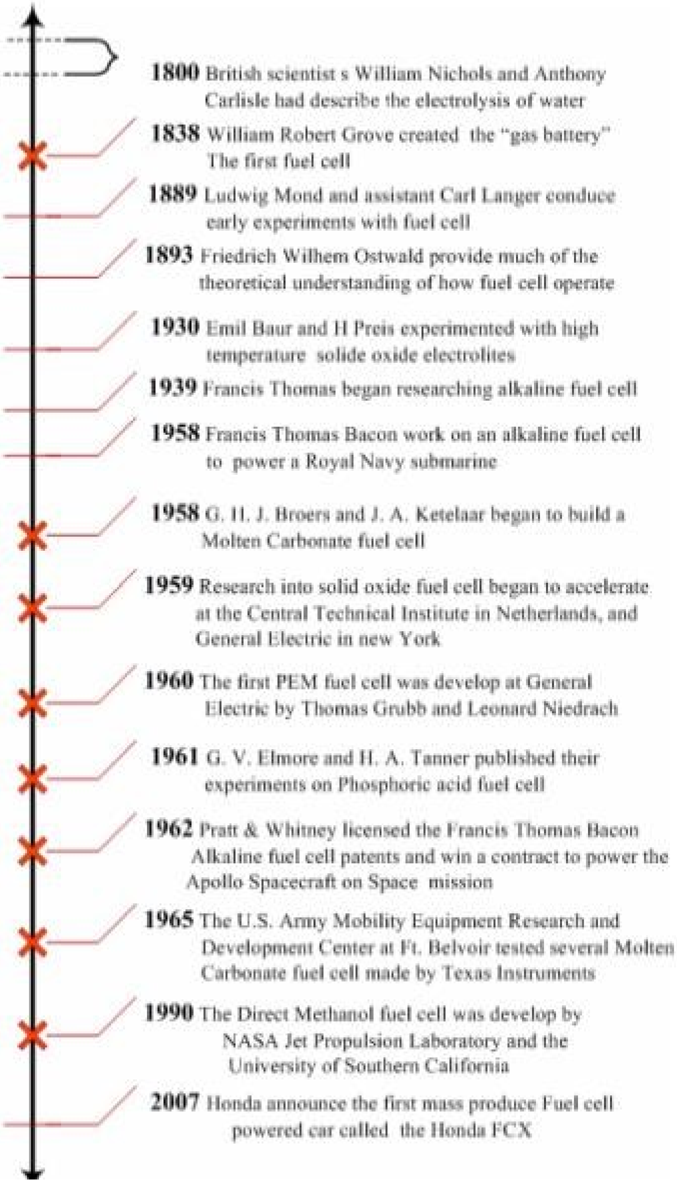


Fig. 3: History of fuel cell until 2007 (Ortiz-Rivera et al., 2007).

3.1 How fuel cell work

A fuel cell electrochemically transforms the chemical energy of a fuel into electrical energy. An electrolyte layer in contact with an anode and a cathode on either side is the basic physical structure, or building component, of a fuel cell. Fuel is constantly delivered to the anode (negative electrode) and an oxidant (typically oxygen from the air) is continuously fed to the cathode in a conventional fuel cell (positive electrode).

Electrochemical reactions occur at the electrodes to generate an electric current that flows through the electrolyte while producing an electric current that works on the load. Although fuel cell system is very similar to a battery, fuel will never out of energy as long as the fuel (usually hydrogen) is supplied. On the other hand, battery will be out of energy after the chemical reactants are consumed. Figure 2 shows how a basic fuel cell works where the fuel supplied in modern fuel cell systems is hydrogen.

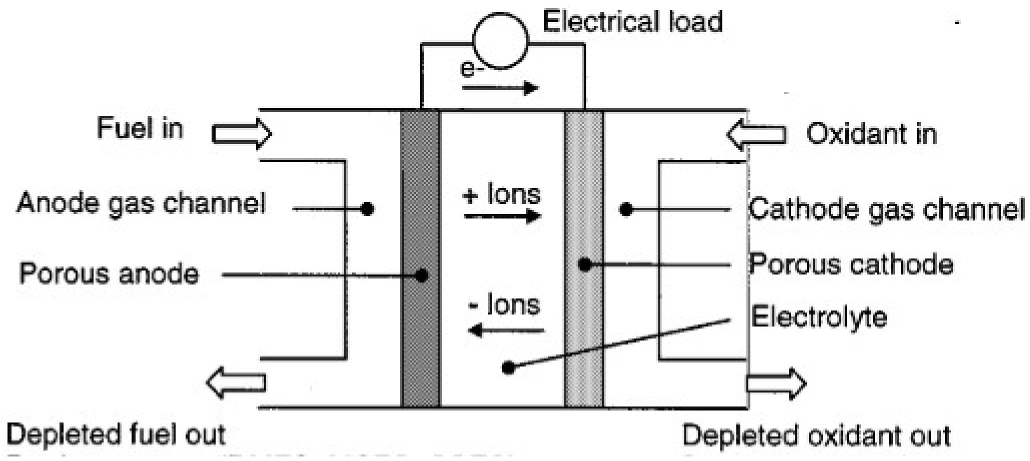


Fig. 4: Basic fuel cell system (Ellis et al., 2001)

3.2 Type of Fuel Cell

Fuel cells classification depended on the type of electrolyte material used (Manoharan et al., 2019). Commonly, there are six main types of fuel cell which are proton exchange membrane fuel cells (PEMFCs), solid-oxide fuel cells (SOFCs), alkaline fuel cells (AFCs), direct methanol fuel cells (DMFCs), phosphoric acid fuel cells (PAFCs) and molten carbonate fuel cells (MCFCs) (Abdelkareem et al., 2021; Belkin & Solovev, 2019; Mallick et al., 2016; Sazali et al., 2020). Table 1 shows the specification in each six main types of fuel cells. Figure 3 shows the efficiency of each type of fuel cell.

Table 3: Specification of each types of fuel cells (Mallick et al., 2016)

	Alkaline Fuel Cell (AFC)	Polymer Electro-lyteMembrane (PEMFC)	Direct Methanol Fuel Cell (DMFC)	Phosphoric Acid Fuel cell (PAFC)	Molten Carbonate Fuel Cell (MCFC)	Solid Oxide Fuel Cell (SOFC)
Operating tem-perature (°C)	< 100	< 120	< 120	160–220	600–800	800–1000
Electrolyte	KOH	Perfluoro sulfonic acid (Nafion® membrane)		H3PO4 immobilized in SiC matrix	Li_2CO_3 –K_2CO_3 eutectic mixture immobilized in γ–$LiAlO_2$	Yttria stabilized Zir-conia (YSZ)
Charge carrier in the electrolyte	OH^-	H^+	H^+	H^+	CO_3^{2-}	O^{2-}
Anode reaction	$H_2+2OH^- \rightarrow 2H_2O+2e^-$	$H_2 \rightarrow 2H^+ +2e^-$	$CH_3OH+H_2O \rightarrow CO_2+6H^+ +6e^+$	$H_2 \rightarrow 2H^+ +2e^-$	$H_2+CO_3^{2-} \rightarrow H_2\ O+CO_2+2e^-$	$H^2+O^{2-} \rightarrow H_2O+2e^-$
Cathode reaction	$½O_2+H_2O+2e- \rightarrow 2OH^-$	$½O_2+2H^+ +2e^- \rightarrow H_2O$	$3/2O_2+6H^+ + 6e^- \rightarrow 3H_2O$	$½O_2+2H^+ +2e^- \rightarrow H_2O$	$½O_2+CO_2+2e^- \rightarrow CO_3^{2-}$	$½O_2+2e- \rightarrow O^{2-}$
Anode electrode	Ni	Pt, PtRu	Pt, PtRu	Pt, PtRu	Ni–5Cr	Ni–YSZ
Cathode electrode	Ag	Pt	Pt	Pt	NiO(Li)	Lanthanumstrontium manganite (LSM)
Realised power	5–150 kW	5–250 kW	< 5 kW	50 kW to 11 MW	100 kW to 2 MW	100–250 kW

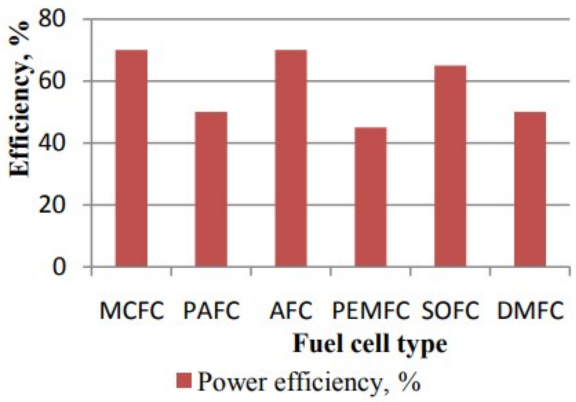


Fig. 5: The efficiency of the fuel cells (Belkin & Solovev, 2019).

4. Batteries Vs Fuel Cells

Generally, batteries and fuel cells work almost the same. Batteries need recharging after a certain period of using time, and fuel cells need fuel, mainly hydrogen, from time to time to function. One of the main issues that always keep people from buying electric vehicles is that the charging time takes too long. At the moment the fastest charging EV battery is produced by LUCID Motors which is 20 minutes using fast charging to reach 300 miles (480 km) of distance (Lucid Air, 2021) compared to fuelling the fuel cells with hydrogen which takes as same as fuelling a conventional internal combustion engine with petrol or diesel.

Another issue that has always haunted EV that use batteries is the range of the EV after full charge (Gnann et al., 2018). Until now, the longest range that EV can go after a full charge is TESLA Model S Long Range with 405 miles (648 km) (United States Environmental Protection Agency, 2021) although Lucid Motors claims that their car can go 520 miles (832 km) in a single full charge (Lucid Air, 2021). These two issues are also connected with the biggest issue that holds back widespread use of EV is charging infrastructure availability, especially when the owner of the EV lives in an apartment complex or condominium. Unless the authority subsidizes the EV maker to build more EV charging infrastructure, this issue will not be solved (Gnann, 2015). The authority can regulate the set up, the infrastructure, and how the infrastructure is deployed (Hardman et al., 2018).

On the other hand, fuel cells have shown some promising features to be the next technology to replace internal combustion engines. Although it has been developed by many automotive companies and successfully tested (Muthukumar et al., 2021), why fuel cell is not yet has become current dominating technology in vehicle, especially in passenger vehicle. Tesla CEO, Elon Musk said that fuel cell technology is “mind-bogglingly stupid” and that it is impossible to make this technology a success (D’Allegro, 2019). So, why fuel cell EV flop? it came down to four simple reasons which are price, convenience, performance, and environment. For most people, a car is the second biggest purchase a person will make after a house. The first thing people will look at when purchasing a car is the price, especially the first time buyer. Usually, the price of a fuel cell EV is much higher than an internal combustion engine vehicle. For example Toyota Mirai price RM277,000 (Lim, 2020). For the same car performance, with internal combustion engine the car price will be under RM100,000. People will have to think more deeply about whether they want to save the planet or want to save their pocket.

Another factor that causes ordinary people to buy fuel cell EV is the cost of hydrogen. Currently, hydrogen is sold as high as $6.80/kg (RM28.40/kg) in the USA (Collins, 2020). Since 1 kilogram of hydrogen has the same amount of energy as 1 gallon of petrol (U.S. Department of Energy, 2020) clearly, filling a fuel cell EV with hydrogen is more expensive than filling an internal combustion vehicle with petrol. Only a few selected individuals are afforded to use fuel cell EVs. Only water is the byproduct of fuel cell EV. Compared to internal combustion engines, fuel cell EV are extremely better for the environment. We will achieve net zero carbon emissions by using fuel cell EVs. The problem today, only 4% of hydrogen production is from renewable sources. Other 96% production still from non-renewable sources such as natural gas, oil, and coal (Yukesh Kannah et al., 2021). Although fuel cell EVs do not produce greenhouse gases, the production of hydrogen still emits massive amounts of greenhouse gases.

Finally, the most important reason that people are reluctant to go by fuel cell EV is because hydrogen does not have many fueling stations. In Malaysia only six hydrogen fuelling stations which is in Sarawak (FuelCellsWorks, 2019) and Europe only have 49 stations (Dispenza et al., 2017). In North America also there are not many fuelling stations also. This will result very inconvenient for the fuel cell EV users and worse than battery powered EV users. The government must set up all the hydrogen fuel station and then people start to by fuel cell EV. Malaysia has developed all the blueprints to become the player of the fuel cell EV in South East Asia (Daud et al., 2017) but the plan is not executed very well.

5. Conclusions

BEV and FCEV at the moment are our best chance to transition from ICE that uses fossil fuel because one day we will run out of fossil fuel and these two types of EVs do not emit any CO2 when it run on the streets. Thus far, BEV has a much better competitive edge because we already have the infrastructure to generate and distribute electricity. We just need to build the power charging station especially fast charging station. Although if we do not have power charging station nearby, we can charge the BEV like we charge our cell phone every night, at home.

Compared to BEV, we still need to figure out how to produce hydrogen cheaper to power FCEV. After figuring out how produce the hydrogen, we must figure out the best means possible to transport the hydrogen by using pipeline or using truck because hydrogen must be compressed before it can be delivered. Other method already been considered and done was building a small hydrogen production plant at site, but this method will increase the price of the hydrogen to power the FCEV.

Unfortunately, most sources to produce electric (Asdrubali et al., 2015) and hydrogen (Kayfeci et al., 2019) are fossil fuel because it is the cheapest way. This means that if life cycle analysis (LCA) study is done to BEV and FCEV, these two types of EV still producing carbon footprint. The authority, industry and NGO must work together to accelerate the transition from fossil fuel dependent to renewable energy before humanity runs out of time.

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