Comparisons Between Fuel Cells and Electric Engines and the Improvements in Engine Technology

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Abstract. In addressing the pressing problem of carbon emissions and their part in the greenhouse effect, this paper emphasizes how important sustainable development is. The emphasis is on the transportation industry, which is responsible for a large portion of carbon footprints because of emissions from conventional combustion engines, which produce large amounts of greenhouse gases, including carbon dioxide, carbon monoxide, sulfur dioxide, and nitrogen oxides. The study presents electric batteries and fuel cells as practical countermeasures. It provides a thorough analysis by diving into the workings, common models, and procedures of these two engine kinds. After that, the study performs a comparison analysis of the benefits and downsides of fuel cells and electric batteries, taking into account several varieties within each category. This report, which offers a comprehensive overview of the current state and possible developments in fuel cell and electric engine technology, is based on experimental data and designs from previous research. Future advancements aimed at producing more eco-friendly and efficient transportation systems will be guided by the insights obtained.

Keywords: Fuel cell, electric engine, transportation.

1. Introduction

In essence, human civilization began when people realized the utilization of energy: pre-historic men found out the maintenance and manipulation of fire instead of directly fetching it from nature, which has a significantly lower probability of occurring and secondary use. The fuel used in this process was mainly wood, the carbon of which integrates with oxygen in the air to form carbon dioxide. Centuries later, with the growth of population and economic development, the Industrial Revolution began, and wood was no longer able to meet the demands. Therefore, fossil fuels such as oil and coal were put into high levels of use. This brings along the invention of the steam engine and, later on, the internal combustion engine, both of which require a large amount of fossil fuel to work. This has led to severe carbon dioxide emissions, thus resulting in increasingly severe environmental issues. The demand for fresh energy will probably rise globally in proportion to the population, which is predicted to double by 2050. Meanwhile, the primary energy demands are anticipated to rise by 1.5-3 times [1].

Governments, academics, and even the general people are now aware of the need for sustainable development. It is defined as “development that meets the needs of the present without compromising the ability of future generations to meet their own needs” [2]. The most essential condition for this to be realized is the supply of sustainable energy resources with higher efficiency. Some strategies for saving energy have been proposed. Energy could be conserved, and efficiency would be enhanced as well; at the same time, some renewable technologies can be proposed, such as solar technology, which is able to increase the capacity incrementally of existing energy systems in the short term [3].

Sustainable development not only requires a sufficient supply of energy but also demands an efficient use of energy resources. In order to achieve this, several steps must be taken, including the energy-saving in transportation. The main approaches are the use of hydrogen as an alternative to fossil fuels, the invention and application of EVs, and technology considering automated driving [2]. Among these innovative technologies, the fuel cell and electric engine act as good examples of applications of sustainable practices. This paper is going to compare the extent to which fuel cells and electric engines contribute to sustainable development and demonstrate the improvement in engine technology in order to achieve this purpose.

2. Working Mechanisms of Electric Engines

2.1. Working Mechanisms of Electric Engines

The electric vehicle (EV) is a suitable alternative to traditional vehicles that produce massive amounts of pollutants when used. They are undoubtedly the future trend of development. Instead of using internal combustion engines and fossil fuels, the electric battery it has acts as the engine of this type of new vehicle. Lithium is a vital component of this technology; when charging, lithium ions travel from the cathode to the anode, and when discharging, they proceed in the opposite direction.

The internal workings of the electric batteries in EVs are depicted in a number of models. As the graph shows, the first one is idealistic, with just a constant voltage source and no consideration for other factors. However, in reality, the capacity of the battery will lower once the load is increased. The second model is a simple to linear battery model, which Kirchhoff's law can explain. As illustrated in Fig. 1, it comprises a resistor and a voltage source with internal resistance. Therefore, the terminal voltage can be calculated by:

$$V_T=V_{OC}-R_{int}\cdot I \tag{1}$$

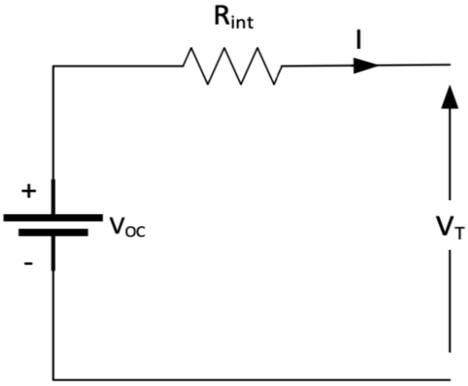


Figure 1. Linear battery model [3]

Where V_T is the terminal voltage of the circuit, R_{int} is the internal resistance of the battery, and I is the current. The influence that temperature, state of charge (SoC), and state of health (SoH) have on resistance—which rises when any of the three drops—is a disadvantage of this technology. A new model considering charging and discharging resistance can be proposed, as depicted in the figure, with the two resistances connected in parallel. Hence, the voltages applied to them are determined by [3]:

$$\text{Charging: } V_T=V_{OC}+R_c\cdot I \tag{2}$$

$$\text{Discharging: } V_T=V_{OC}-R_d\cdot I \tag{3}$$

The separate work of two resistors does the processes of charging and discharging. When the circuit is in the charging state, the diode in the charging resistance is polarized, while that in discharging resistance is reversely polarized, blocking the current flow. The discharging process follows the opposite pattern, with only discharging resistance being activated and put into use [3]. The models introduced above are basic ones, and the following paragraphs will mainly focus on the detailed mechanisms of several electric battery models. Thevenin-based batteries are the subject of this discussion's first model. First-order, second-order, and third-order categories are available for it. They are capable of dealing with transient state simulations [3]. The first-order Thevenin often called a onetime constant (OTC), consists of an internal resistance, an RC pair with R1 and C1 connected in parallel, and most importantly, a voltage source. It is a relatively simple model of this kind, as shown in Fig. 2.

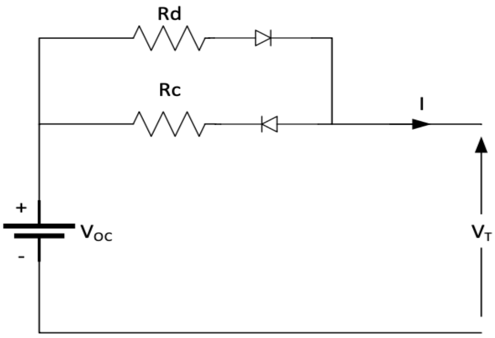


Figure 2. Model with charging and discharging resistors [3]

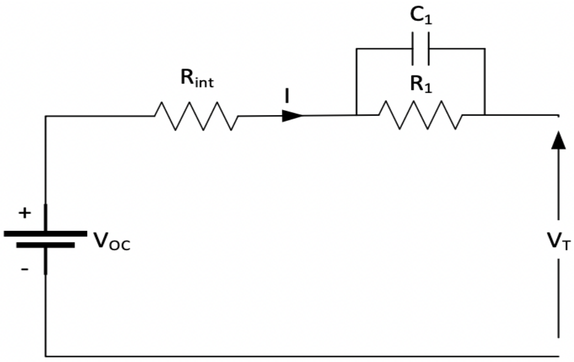


Figure 3. First-order Thevenin model [3]

Following up is the second-order Thevenin model, also referred to as two-time constants (TTC), as depicted in Fig. 3. In this model, there are two RC pairs (a pair of R2 and C2 are added). When the current is zero, it may precisely depict the terminal voltage. The terminal voltage can be calculated by [3]:

$$V_T=V_{OC}-R_{int}\cdot I-V_{C1}-V_C \quad (4)$$

In specific:

$$V_{c1}=-1/R_1\cdot C_1+(1/C_1)\cdot I \quad (5)$$

$$V_{c2}=-1/R_2\cdot C_2+(1/C_2)\cdot I \quad (6)$$

Similarly, a third-order Thevenin model employs a third pair of resistance and voltage cells. Despite this, all the other layout of the circuit is the same as the second-order Thevenin model, and the voltage across each resistor is also calculated in the same way.

Apart from the Thevenin models, there is the EECM model, which is shown in Fig. 4. It makes use of resistors, capacitance, and supply voltage, among other electric components. Occasionally, this combination will also include a linear component, like a Warburg impedance [4]. The first classification is based on impedance. The electrochemical impedance is its definition of the response to an applied voltage from an electrochemical system [3] and is determined by producing a little AC to pass through the battery that is the subject of the researchers' inquiry [4]. EIS is the shortened form of electrochemical impedance spectroscopy. It refers to the impedance in a specific range of frequencies of AC. In order to set the operational point (including battery impedance changes with the state of charge, temperature, direction, and amplitude of DC) and ensure the system is properly under control, a superimposing DC is occasionally called in for aid. Randle’s EECM model is in a simplified form, as shown in Fig. 4. Internal resistance is represented by Ri, inductance by L, capacitance by C, nonlinear resistance by R, and constant nonlinear Warburg impedance by Zw, which is calculated by:

$$Z_W=A_W/\sqrt{w}+A_W/j\cdot\sqrt{w} \quad (7)$$

Where A_w represents the Warburg coefficient, w stands for angular frequency, and j is the imaginary number.

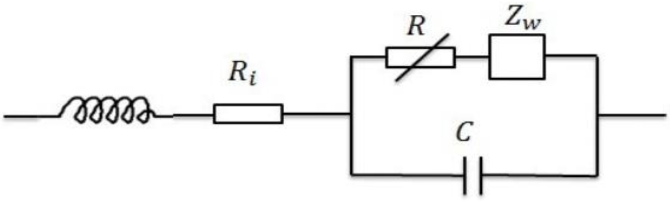


Figure 4. EECM model [4]

There is a second type of EECM is V-I based. It is a linear EECM structure without the potential negative impact of nonlinear elements. The structure can be seen in Fig. 5. It has an internal resistance, an optimal voltage source, and many series-connected RC networks that are utilized to record the dynamics of battery action [4]. However, because a single constant EECM is too nonlinear and non-stationary to adequately explain the battery behavior over a wide range of the SoC, temperature, and current rate, a linear parameter variable (LPV) system is suggested, which can function in a variety of scenarios. LPV makes it simpler for engineers to configure and recognize the parameters, being precise for the majority of system design applications due to its interoperability with other software. The arrangement of an m-th order LPV EECM is shown in Fig. 5, where v and I stand for the terminal voltage and current, respectively [4].

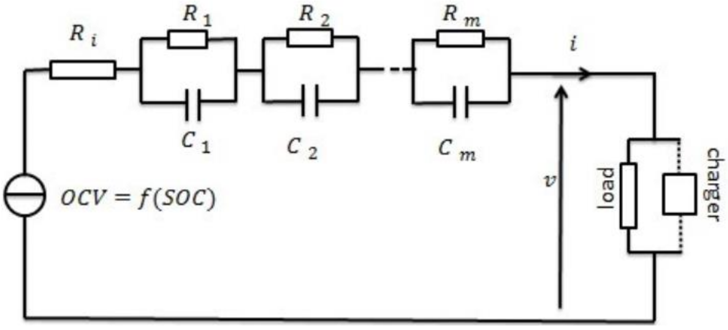


Figure 5. Linear EECM model [4]

In conclusion, a wide variety of models are utilized to illustrate how an electric battery works. The primary issues at hand pertain to external factors that have the potential to impact voltage output, including but not limited to temperature, internal resistance, current flow rate, and the nonlinear properties of specific parts. However, as technology advances and more reliable models are consistently proposed by researchers, accuracy will see a major improvement in the future.

2.2. Working Mechanisms of Fuel Cells

In theory, the fuel cell is an electrochemical instrument that can directly transform the chemical energy of an oxidant and a fuel into electrical energy [5]. The fuel cell will go through a number of chemical reactions to attempt to convert the energy. The general functioning of a fuel cell can be described by the Nernst reaction [6]:

$$j=j_{0}[\exp(\mathring{a}AnF\eta/RT)-\exp(-\mathring{a}_{c}nF\eta/RT)] \tag{8}$$

The potential diverges from the equilibrium position when a current passes by. Moreover, the excess potential η is represented by this divergence. For the anodic process, j is the current density, j0 is the exchange current density, and åc is the transfer coefficient [6]. The variation between the two half-cell potentials and an extra ohmic drop is the fuel cell's cell voltage. Fig. 6 depicts the relationship between power density and current density, making it useful in representing comparisons between various fuel cells.

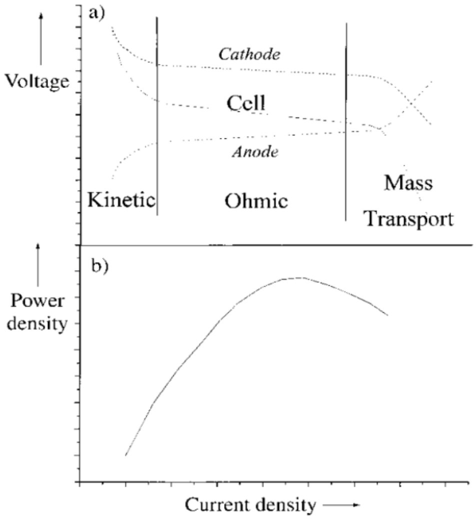


Figure 6. (a) The anodic and cathodic reactions' contributions to the cell voltage show the mass, ohmic, and kinetic transport areas. (b) A power density vs the current plot can be obtained using the current-voltage data [6]

The fuel cell can be divided into several types. The following paragraphs will mainly focus on the working mechanisms of different classifications. Out of all the varieties, the alkaline fuel cell (AFC) has the best productivity. However, its primary flaw is that it is limited to extremely clean gasses, as the high reactivity of OH^{-} with carbon allows it to react with the slightest quantity of CO_2 [5]. The reactions in an alkaline fuel cell take place with the assistance of a KOH electrolyte, which is especially useful when it comes to acidic fuel cells. As shown in the figure, catalyst layers need to be placed on the two sides with anode and cathode. Then, the exchange of hydrogen gas, oxygen, and gaseous water occurs with the existence of hydroxide ions. In Fig. 7, the operational mechanism is displayed.

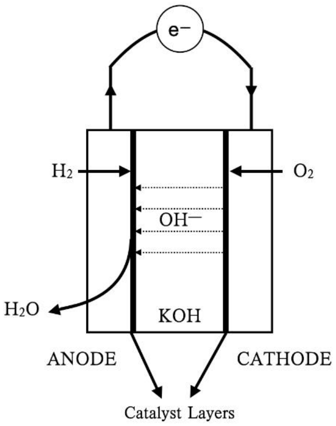


Figure 7. Working mechanism of an AFC [5]

Both hydrogen oxidation and reduction, including the production of OH— ions, occur in alkaline media. The OH— ions created during the cathodic removal of water travel through the electrolyte to the anode, where they recombine with hydrogen and undergo oxidation to produce water at the other end. The reaction occurring at the cathode is given by:

$$1/2O_2+H_2O \longrightarrow 2OH^{-} \tag{9}$$

The following provides the anode's reaction:

$$H_2+2OH^{-} \longrightarrow 2H_2O+2e^{-} \tag{10}$$

Thus, the general reaction can be written as:

$$H_2+1/2O_2 \longrightarrow H_2O \tag{11}$$

Compared to the process of reducing O_2 to H_2O, the reduction of oxygen to OH^- occurs significantly more quickly due to improved kinetics. In order to transform a fuel cell's chemical energy into electrical energy, all of the electric components are crucial. Among them, electrolytes are a key part of the whole system. It has been proven that keeping the KOH flowing could result in noticeably longer operational longevity. It serves as a source of coolant in the compartment and stops some possible gas leaks. It can also eliminate water from the anode side while cleaning the cell.

Furthermore, the development of carbonates is a problem that is frequently raised. It is believed that the carbon dioxide in the reaction can interact with the electrolyte. The reaction is as follows:

$$CO_2+2OH^- \longrightarrow CO_3^{2-}+H_2O \tag{12}$$

The carbonates produced can block the gas diffusion electrodes' pores, which further influences the overall performance of the cell, but the circulating electrolyte stops this from happening. Molten carbonate fuel cells, or MCFCs for short, are another kind of fuel cell. The benefits of MCFCs are quite obvious. Not only does it produce no CO_2 when it operates, but they are also able to reform the methane internally because of the high temperature ranging from 600˚C to 700˚C when operating. Moreover, the waste heat is useful in raising the kinetics of oxygen reduction, sparing the need for high loading and precious metal as a catalyst in the reaction. As shown in Fig. 8 shows the chemical events that occur in a molten carbonate fuel cell running on either methane or hydrogen.

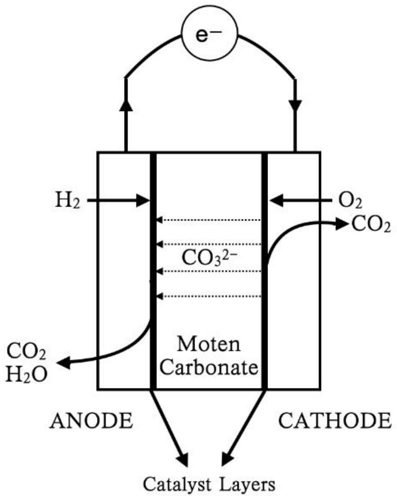


Figure 8. Working mechanism of an MCFC [6]

The normal half-cell reactions in the MCFC can be divided into two parts. In the anode, hydrogen is oxidized by carbonate ions, and water and carbon dioxide are produced in this process:

$$H_2+CO_3^{2-} \longrightarrow H_2O+CO_2 \tag{13}$$

The products then further react:

$$1/2O_2+CO_2+2e^- \longrightarrow CO_3^{2-} \tag{14}$$

A third design is the solid oxide fuel cell (SOFC). Compared to MCFCs, it employs a solid oxide material so that no leakage problem would occur. The system of SOFC is straightforward with two phases, having no concerns about water control, catalytic layer flooding, and retarded oxygen reduction kinetics. However, suitable materials are quite difficult to find due to the requirements of high thermal and chemical stability. The schematic representation is depicted in the figure [6]. A more specific depiction of the structure can be illustrated in Fig. 9:

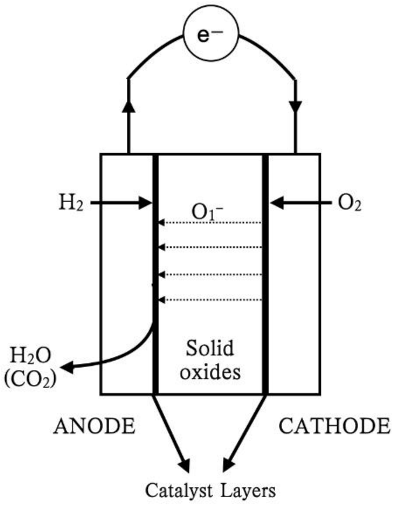


Figure 9. Working mechanism of a SOFC [6]

The working principle of the SOFC is simple. It supplies air to the cathode with the addition of four electrons. O_2 molecules are split into oxygen ions in the cathode. Following that, they are moved to the anode via the electrolyte, where they interact with the delivered hydrogen to give off more electrons and produce hot water [5]. The anode gathers the former. The working mechanism is depicted in Fig. 9, and a more detailed illustration is in Fig. 10.

The electrolyte of the SOFC is always a controversial subject among researchers. The material to make it must possess strong mechanical properties, chemical stability, and good conductivity of ions, even though high temperatures must be reached to achieve the required conductivity. Therefore, efforts are made to select the most proper material. Scandium-doped zirconium and gadolinium or samarium-doped cerium oxide are current candidates for it, but problems such as high cost and difficult conditions still exist [5]. In spite of the challenges in the fuel cell industry, SOFC is still a viable option for full commercialization [5].

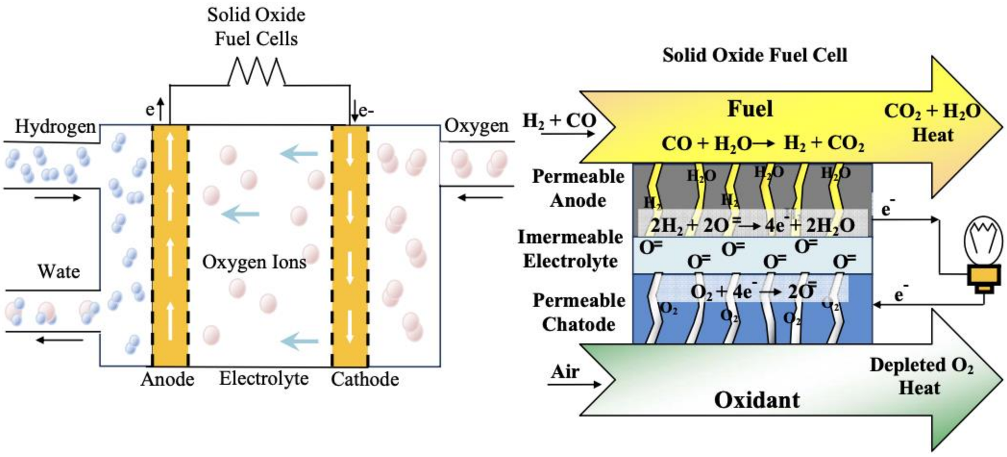


Figure 10. Detailed working mechanism of a SOFC [5]

3. Analysis of Advantages and Disadvantages

3.1. Advantages and Disadvantages of Electric Engines

Electric cells located within battery electric vehicles (BEVs) power the motor that drives them, which is also their internal source of energy. To increase the energy efficiency of the EV, many manufactured solutions make use of energy recovery technology, allowing motors to be used as both propulsion sources and generators while braking or moving freely under the action of gravity [7]. This can significantly increase the overall efficiency of EVs.

3.1.1 Advantages of electric engines

A battery-electric vehicle's strong torque delivered to the tires is its primary benefit. In addition, smoother acceleration as well as deceleration is another advantage of TVs powered batteries. Moreover, BEVs operate without any noise or pollutant emissions. However, they are still burdened by many disadvantages, including high production costs, restricted top speed and autonomy, massive recharging connections, and the requirement for specific charging locations [8].

The life cycles of EVs and batteries are crucial in assessing the efficiency and advantages of using electric engines. The LCA approach is an important method used to evaluate the effects of the duration of a technology compared to another one or the external environment. The LCA systemic structure for the battery is depicted in Fig. 11 [8].

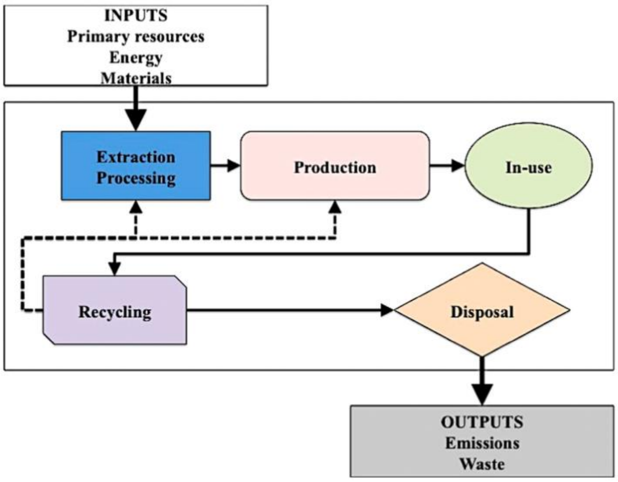


Figure 11. LCA systemic structure for EV batteries [8]

Among all, lithium-ion batteries are mostly favored as they possess a relatively high energy density, being used widely in EVs. The excellent performance of the lithium sum battery material is one of this particular kind of battery's main advantages. The three components of a lithium-ion battery are the electrolyte, cathode, and anode. The cathode materials, which mostly consist of ternary lithium ions, lithium cobaltate, lithium iron phosphate, and lithium manganates, have a high energy density; the energy density increases with the amount of nickel present in the positive electrode. However, it also presents a challenge: structural integrity and thermal resilience will likewise decline with an increase in nickel content [9]. In order to fulfill the driving range, most manufacturers use large-capacity batteries. High-niche ternary materials are, therefore, frequently used. On the other hand, ternary lithium-ion has an elevated density of energy and good low-temperature achievement, so it is generally used in automobiles for passenger use. $LiFeO_4$ has a high cycle life as well as outstanding security, so its usage is frequently observed in buses and commercial automobiles [9].

The high performance of anode materials is also very important in the changing process. It is essential for both the release and storage of energy. Good conductivity and conductive ions are mostly needed for this component in order to reduce polarization and increase current recharge and discharge [9]. Thankfully, lithium-ion batteries can supply this component's requirement. When the solid electrolyte interphase, or SEI, forms, the insert does not react with the electrolyte because it is chemically stable within the range of the whole voltage. Moreover, the diffusion coefficient of lithium ions is very large, so the charging and discharging process can be quickly carried out. The material of the anode is capable of forming a robust SEI layer connected to the liquid electrolyte by means of an excellent exterior structure [9].

The electrolyte exists in the same between the battery casing, the separator, the anode, and the cathode, functioning as a conductor of lithium irons. It plays the role of enhancing the devices' cycle efficiency and energy density. The electrolyte's capacity and voltage determine the energy density of a lithium-ion battery. New technological requirements for the high-voltage performance of the electrolyte are presented by the higher operating voltage's positive energy density and enhanced strength of the anode and cathode materials [9]. Among the several kinds of electrolytes, the inorganic solid-state electrolyte has strong ion conductivity and good thermal resistance, as well as poor electrical conductivity. Good thermal stability in a battery made of lithium-ion helps address possible safety concerns [9].

3.1.2 Disadvantages of electric engines

Although electric engines have many advantages, they are still burdened by various limitations that still need improvement in the future. The first disadvantage is the environmental burdens. There are not many comprehensive LCA studies out there that provide thorough inventories. The environmental impacts associated with battery production and use are the focus of much scientific debate, revealing pertinent carbon dioxide equivalent emissions of a wide range. However, since a lithium-ion battery only contains 1% lithium, approximately 80 grams for every kilowatt energy content, these changes are only partially caused by battery chemistry and, least of all, by the metal lithium [10].

Moreover, another type of battery, the $LiFePO_4$ battery, has a component of 42% iron, 16% phosphorous, 5% of graphite, 3% of carbon element, 6% of aluminum and 10% copper. The materials graphite, copper and aluminum are of the highest relevance to the anode and cathode in the battery. Additional researchers looked into how a $LiMn_2O_4$ battery affected the environment. As a result, the environmental burden for the two more frequently used active materials showed only a slight increase of 12.8% (Li-Mn-Ni-Co-O_2) and a decrease of 1.9% ($LiFeO_4$) [10]. Future production can lessen its carbon footprint by shifting to locations like Iceland, which has abundant geothermal energy [10].

The second disadvantage is the impact of CO_2 on the life cycle of the battery EVs. It is reasonable to anticipate that conventional automotive parts' carbon emissions and environmental effect measurements will produce less erratic data than Li-ion batteries. Either the indirect carbon dioxide emission during the production of electricity or the carbon emission from the car's fuel consumption can be used to quantify the carbon emissions during battery manufacture. As shown in Fig. 12, the result is presented to show the carbon dioxide life cycle analysis using a modified Smart vehicle [10].

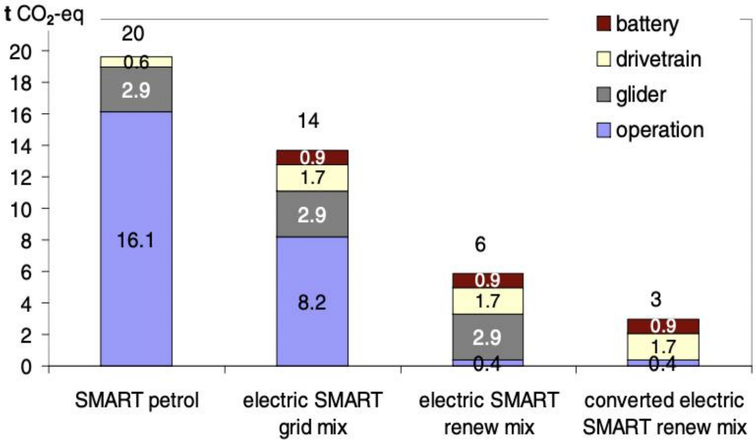


Figure 12. Quantified carbon emission during battery production [10]

Other than environmental impacts, there are also some challenges in putting this technology into production. Linking the various physical processes in a single model is the first issue [11]. This is due to the fact that multiple physical processes, including material breakage, short-circuit generation, current circulation, and thermal propagation, may occur simultaneously during a typical battery failure event. Liquid electrolytes can potentially impact jellyrolls' mechanical performance. Because of this, variables like coupled mechanical, thermal, and fluid responses must be considered in a single model [11]. So-called state-of-the-art models ignore the influence of electrolytes despite the fact that they can have many solvers and record key aspects of battery failure. Apart from the non-physics-based model, their scope of use is restricted [11]. Accurately measuring and simulating complicated material properties is another issue [11]. Typically, a battery cell has hundreds or even thousands of tiny layers, each with unique features. The characteristics are temperature-dependent and can be strain-rated. They are also readily impacted by electrolytes and have the potential to be anisotropic [11]. Furthermore, each component's failure mode and short-circuit state should be fully understood in order to identify a failure of the battery. Because of a cell's intricate loading and boundary conditions, measuring these conditions is difficult [11].

3.2. Advantages and Disadvantages of Fuel Cells

In theory, the fuel cell is an energy-conversion device that can generate electrical energy as long as the electrodes are supplied with fuel and oxidants.

3.2.1 Advantages of fuel cells

The initial benefit of fuel cells is that it has higher volumetric and gravimetric efficiency. This is so because the fuel consumed directly produces electric energy. Because of this, fuel cell technology is unaffected by the Carnot Cycle's constraints [6], which primarily afflict all combustion-based electric generation systems. The second advantage is that fuel cells produce little chemical, acoustic and thermal emission. The emission from fuel cells contains less CO_2 and NO_x compared with other engines. This is the consequence of the higher efficiency mentioned above, as well as lower fuel oxidation temperature. In terms of noise and vibration, these two factors can be almost neglected as all the parts in fuel cells are stationary when working, aside from the blowers, transformers, and auxiliary pumps [6].

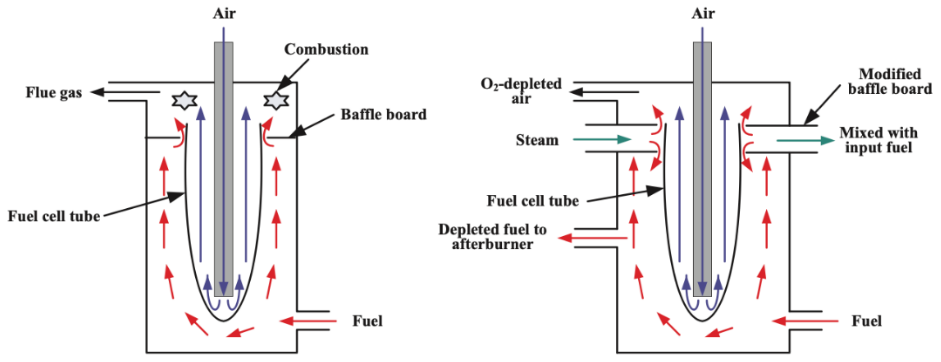
The third advantage is the modularity and seating flexibility. Less than one voltage of electrical energy is produced by a single fuel cell. A method to increase the overall potential difference that fuel cells produce is to stack a number of fuel cells on top of each other. A stack comprises repeating fuel cells, each consisting of two electrodes, a bipolar separator plate and a single electrolyte. The total amount of fuel cells in a stack is determined by the intended power output of the stack [6]. The stack can have a power output between a few hundred watts to several million watts.

The fourth advantage is the fuel flexibility. With low-temperature fuel cells, hydrogen gases, especially the ones with extreme purity, are the most commonly used. On the other hand, numerous technologies that employ coal gas, landfill gas, natural gas, propane, and military fuels have shown to be fuel flexible. Operative temperature determines the flexibility of the majority of fuel cell types; essentially, the purity of the gas the fuel cell can use forms a negative relationship with the temperature of the cell [6].

The fifth advantage is its many roots in environmental concerns. Various types of fuel cells are capable of carbon capture and the emissions from fuel cells can be significantly reduced.

The first type is the molten carbonate fuel cell (MCFC) capable of carbon capture. The process of reaction states that an MCFC can extract carbon dioxide from burned flue gas by using it as a feed on the cathode side. After that, at the positive electrode, CO_2 is changed into CO_3^{2-}, which then passes through the molten carbonate electrolyte to reach the negative electrode. The electrolyte travels with charged ions to produce the power required for functioning. [12]. Furthermore, for cleansing, the CO_2 accumulates at the anode exit. This carbon dioxide is easier to capture since it is an order of scale higher than the exhaust fumes in the cathode entrance [12].

The second type is the solid fuel cell with carbon capture (SOFCs). One unique feature of SOFCs is that fuel conversion takes place without the need for nitrogen to dilute carbon dioxide. As a result, the SOFC anode flow has a larger carbon dioxide component than an average combustion power plant [12]. Fig. 13 compares the tubular SOFC system with exhaust gas flow and with or without carbon capture.



No CO_2 capture

With CO_2 capture

Figure 13. SOFCs with and without carbon capture [12]

In an SOFC module, the gases are exhausted by the anode and cathode through the carefully regulated baffle board leakage. The cathode's off-gas chamber is where combustion occurs when the anode's waste gas enters inside. This is only the situation for regular SOFCs. The anode and cathode off-gases in SOFCs with carbon capture systems need to be properly segregated. In the meanwhile, a dependable method for preserving the separation of those streams is recommended: creating a steam buffer plenum between the anode exhaust gas flow and the cathode waste gas stream [12]. The suggestion of separating the anode and cathode off-gases using the flue gas, which is high in carbon dioxide and water, rather than using alternative steam suppliers for certain arrangements, can also be implemented in those systems as well. Because of its elevated temperature, SOFCs can be used with other types of fuel cells to create hybrid engines [12]. Fig. 14 shows the working mechanisms of an integrated system that is most commonly used.

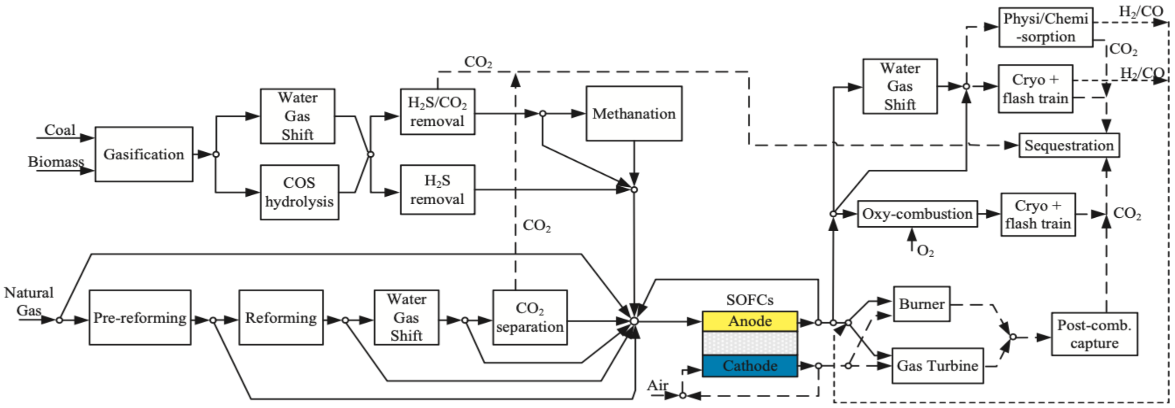


Figure 14. Working mechanism of the current integrated system [12]

3.2.2 Disadvantages of fuel cells

Fuel cells offer many remarkable properties, although they are still in the early stages of development. Therefore, some of their characteristics are still in need of improvement as there still exist problems such as production, storage, and transport problems for hydrogen. Methanol is considered a fairly competitive fuel due to many shared physical and chemical qualities with gasoline, the conventional fuel used in combustion engines. However, large-scale production is still an existing problem even for methanol. Moreover, widespread maintenance and repair facilities are in great need as they are a new technology and do not possess the properties that hybrid EVs have. This is because HEVs have an unavoidable advantage that they can use the already-existing infrastructure for conventional ICEVs [13].

Removing sulfur from hydrocarbon fuels either before or after reformation is the second issue. Ultra-clean fuels are needed to satisfy the fuel cell applications and to tackle the environmental issue. However, even with the termed exceptionally-low sulfur clean fuels, which meet the regulations by having sulfur contents less than 15 ppmw in diesel fuel and less than 30 ppmw in gas, the sulfur concentration is still too high for the intended use [14]. In order to prevent sulfur toxicity of the

PEMFC catalyst and to remove sulfur from the fuel before or after reformation before the reformat flows to the water-gas-shift reactor, researchers still need to perform certain treatments. However, although some developers are now employing sulfur traps prior to or afterwards the reformer, others disregard the sulfur removal process, believing that refineries would generate sulfur-free or extremely low sulfur fuels immediately as fuel cells are marketed [14]. For fuel cell applications, selective absorption can be used as an organic sulfur trap to remove sulfur from fuels before the reformer, either onboard or on-site. Thus, more development is necessary [14].

The next challenge is the application of fuel cells in transportation. The onboard reformation of hydrocarbon fuels for automobiles could play a significant role in fuel treatment for the creation of hydrogen in the near term [14]. A thin covering of palladium has been placed on the outside of porous ceramics by researchers to produce a composition membrane. With 100% effectiveness, only hydrogen can pass through the barrier when this layer fully covers the surface. Some other studies have also been carried out to ensure the purity of hydrogen, but more efforts need to be made to provide a solid foundation for the safe application in transportation in the future [14].

4. Conclusion

The primary conclusions of this essay center on the necessity of sustainable development, the advancement of transportation systems, the advancement of engine technology, and the functioning principles of the two primary combustion engine substitutes, fuel cells and electric batteries. An examination of the benefits and drawbacks of each technology follows these findings. In specifics, electric batteries can be divided into multiple models, such as the EECM model, the Thevenin model series, and the linear battery model with an enhanced version. There are other varieties of fuel cells as well, like AFC, MCFC, and SOFC, but they are all based on the same reaction equation and consist of an electrolyte, a catalyst layer, and two electrodes. The advantages of electric batteries are mainly due to the high torque of their wheels, and Li-battery is most focused in the paper with outstanding features of anode materials, diffusion coefficient, and electrolyte; the disadvantages are due to environmental burdens and carbon dioxide impacts. Conversely, fuel cells offer the following benefits: reduced chemical, acoustic, and thermal emissions; increased fuel flexibility; modularity and seating flexibility; and the capacity to trap carbon dioxide.

Nevertheless, this paper's research has many shortcomings as well. The most evident is that numerous elements that might be present in real-world use were ignored in favor of not conducting experiments and evaluations in actual life. The second drawback is that additional details about conventional combustion engines should be included, along with greater linkages between the two categories of engines. These two constraints stem mostly from the inability to use experimental resources and the restricted availability of internet information. Future research will be conducted more methodically—perhaps in multiple studies—to gain a deeper comprehension of the advancements made in engine technology over the years.

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