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Original Research Paper

# PEMFC Technology as a Mobile Generator and Back-Up Power Supply Environmentally Friendly

**Enggik Dwi Pamungkas[1], Fajar Wahyu Kurniyanto[1], Fariz Aditya Putra[1*], Helena Trisa Rani Marpaung[1], Silvia[1], Bambang Priyono[2]**

[1] *Department of Energy Systems Engineering, Faculty of Engineering, Universitas Indonesia. Jakarta, Indonesia.*
[2] *Department of Metallurgical & Materials Engineering, Engineering Faculty, Universitas Indonesia. Jakarta, Indonesia.*

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***Corresponding Author:**
Fariz Aditya Putra
**Email:**
farizaditya20@gmail.com



**Abstract**: Hydrogen as a renewable energy source is increasingly important in efforts to reduce carbon emissions and transition to clean energy. Many power plants are equipped with hydrogen plants that produce hydrogen gas continuously, but excess hydrogen is often disposed of when storage reaches maximum capacity. This study proposes the use of excess hydrogen to power fuel cells as a backup energy source in various important facilities, such as commercial centres, fitness, and health services. Hydrogen fuel cells offer the main advantage of zero-emission operation, making them an ideal solution for improving energy sustainability. By using previously discarded hydrogen, not only energy waste can be minimized, but it also opens new business opportunities in the sale and rental of fuel cell systems to consumers who care about their carbon footprint and clean energy. The hydrogen gas productivity at a power plant reaches 88.8 kg/day, and the potential excess hydrogen gas at a power plant reaches 48.84 kg/day. One kilogram of hydrogen gas can generate 15 to 20 kWh of electrical energy. The study also examines potential business models that focus on the utilization of hydrogen from renewable energy sources such as solar, hydro, and geothermal. In addition, the analysis shows that the application of fuel cells for backup energy systems in strategic locations can reduce dependence on conventional energy that generates emissions. The use of this technology has great potential to support green energy infrastructure in Indonesia and is in line with global initiatives towards reducing carbon emissions. With the cost of hydrogen production getting lower and the growing awareness of the importance of clean energy, this approach is expected to play a significant role in achieving sustainable energy targets.

**Keywords:** Carbon Emissions, Clean Energy, Fuel Cells, Hydrogen, Renewable Energy.

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## 1. Introduction

Hydrogen is an important solution in the clean energy transition, especially in supporting renewable energy systems such as solar and wind power. One of the advantages of hydrogen is its ability to store excess energy generated by renewable power plants, which generally experience fluctuations in production. When the production of renewable energy is greater than the demand, the energy can be used to electrolyze water into hydrogen and oxygen. The hydrogen produced can then be stored and reused when energy demand is high, or it can be converted into electricity through fuel cells by producing only water as a by-product [1].

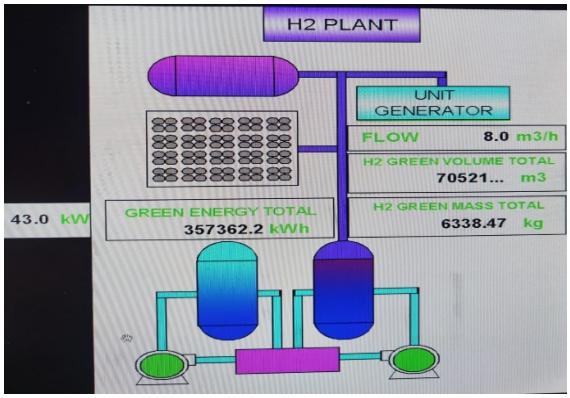


Figure 1. Dashboard of $H_2$ Plant

Hydrogen fuel cells are one of the most efficient technologies for utilizing hydrogen as an energy source. Fuel cells work by reacting hydrogen and oxygen inside a cell to produce electricity, heat, and water. One of the main advantages of this technology is its higher efficiency compared to burning fossil fuels, as well as the absence of carbon emissions or other pollutants during the process. In addition, hydrogen fuel cells have a wide range of application potential, ranging from vehicles, industry, to as an energy storage system for the power grid. While hydrogen has many advantages, the main challenge in the adoption of this technology is the expensive storage and distribution infrastructure. Hydrogen storage systems require large investments, mainly due to the nature of hydrogen that requires very specific storage conditions (high pressure or low temperature). However, various efforts to improve the efficiency of hydrogen storage systems and reduce infrastructure costs continue to grow, including the development of proton exchange membrane (PEM)-based water electrolysis methods that allow for faster and more efficient hydrogen production [2].

In an economic context, the cost of producing hydrogen through renewable energy (known as "green hydrogen") tends to decline as technology develops and production scales increase. In addition, with the increasing number of renewable energy plants, such as solar and wind power plants, hydrogen can be one of the main solutions for storing energy and meeting energy needs in a sustainable manner. The use of hydrogen can also help reduce dependence on fossil fuels and significantly reduce carbon emissions.

The applications of hydrogen are not limited to energy storage. Hydrogen is also used in a variety of industries, such as ammonia production, metal processing, and heavy transportation. In energy systems, hydrogen can function as a buffer in the electricity grid dominated by renewable energy sources, where hydrogen can be converted back into electricity using fuel cells or used directly as fuel [3]. Thus, hydrogen has great potential to support the clean energy transition and serve as an efficient energy storage and alternative solution for fossil fuels in various industrial and energy sectors. However, the success of its implementation is highly dependent on the development of infrastructure and supportive policies.

## 2. Literature Review

Hydrogen distribution and the application of Proton Exchange Membrane Fuel Cell (PEMFC) technology play an important role in supporting the clean energy transition. However, challenges in hydrogen storage and transportation remain a major obstacle [4]. Because hydrogen is flammable and requires specialized infrastructure, the delivery of hydrogen from the point of production to the end

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user, both at refuelling stations and power generation facilities requires a rigorous process. This process includes various stages ranging from production, storage, compression, to safe distribution. Each of these methods has different advantages and disadvantages depending on the distance, volume, and available infrastructure [4].

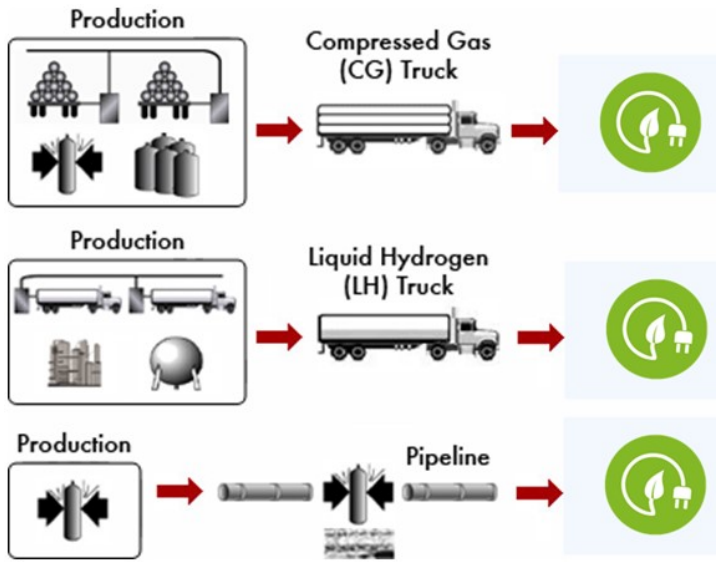


Figure 2. Distribution of Hydrogen to Fuel Cells

Distribution of hydrogen to fuel cells are:

1) Compressed Gas (CG) Truck:
   Hydrogen is produced and stored in the form of a compressed gas. After that, the hydrogen is transported using trucks equipped with high-pressure tubes. These trucks then deliver hydrogen to filling stations for hydrogen-fuelled vehicles (such as cars). This method is suitable for medium to short distance distributions.
2) Liquid Hydrogen (LH) Truck:
   Hydrogen is produced in liquid form after a cryogenic process that cools hydrogen to its melting point. Cryogenic tank trucks are used to transport liquid hydrogen to filling stations. Liquid hydrogen is more efficient for long-distance transportation because in liquid form, hydrogen can be stored in smaller volumes than in gaseous form.
3) Pipeline:
   Hydrogen can also be transported via pipelines from the production site directly to the filling station. It is the most efficient method for long distances and large volumes, but the current hydrogen pipeline infrastructure is still limited in many regions.

The distribution of hydrogen also depends on the existing infrastructure. In some countries, such as in the US, distribution through hydrogen pipelines is very limited and is mostly carried out in large industrial areas. A more commonly used method is transportation using trailers or tankers, depending on operational needs and distance. Each method has its own advantages depending on the delivery distance and the available infrastructure. Distribution through compressed and liquefied gas trucks is often used in areas with high local demand, while pipelines are more suitable for mass distribution over a wider area.

Filling hydrogen in tubes on pallets for distribution by truck involves a safe and efficient process, which is regulated by various distribution and filling methods. This distribution process involves a series of steps that must be carefully carried out to ensure safety and efficiency [5]. First, before filling, all hydrogen cylinders or cylinders attached to the pallet should be thoroughly inspected to ensure that there are no damage or leaks. Each tube must also meet applicable safety standards. The

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tubes are then connected to the hydrogen filling system using the appropriate hoses and valves, ensuring that all connections are tightly closed to prevent gas leakage.

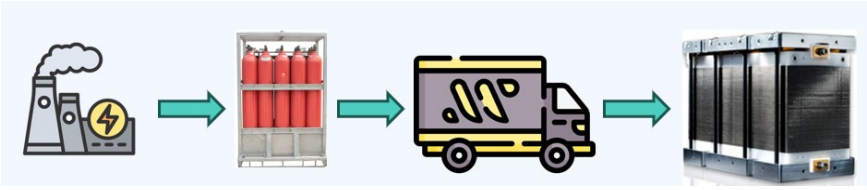

Figure 3. Hydrogen Distribution

The hydrogen filling process is carried out using a special compressor to put hydrogen into a tube with high pressure, usually between 200 and 700 bar. This filling must be done with extreme caution to prevent overfilling which can be dangerous. During filling, the temperature and pressure in the tube must be carefully monitored as compressed hydrogen can cause an increase in temperature [6]. In some cases, cooling or temperature control is necessary to maintain safety. Once the filling is complete, the pressure in each tube is rechecked to ensure it complies with the set standards. The valve closure is done tightly, and a final inspection is carried out to ensure there are no leaks in the joints. After that, the pallet containing the hydrogen cylinder should be labelled with relevant information such as the amount of hydrogen, pressure, and filling date. This labelling is important for tracking purposes and compliance with distribution regulations. Once all safety procedures have been met, the hydrogen-filled pallets are ready to be distributed to the destination using vehicles equipped with special safeguards for the transport of high-pressure gases. This process must always be carried out by trained technicians and in accordance with the safety standards set by regulatory bodies for hydrogen management. Upon arrival at the destination location, such as a hydrogen refuelling station, industrial plant, or storage facility, the pallets are unloaded and prepared for further use. In a hydrogen refuelling station, for example, the hydrogen in a pallet can be transferred to the station's storage tank, where the hydrogen is then used to fill the hydrogen vehicle. This process enables the efficient and safe distribution of hydrogen from the plant to the end user, by utilizing modern logistics technology and low-emission transport vehicles to support the clean energy transition.

However, pallet distribution still faces challenges, such as limited capacity compared to other transportation methods such as hydrogen pipelines, and the need for suitable infrastructure at each distribution location. Nonetheless, additional technologies such as security sensors and smart pallets can improve the safety and efficiency of distribution by providing real-time information about hydrogen conditions and pressures during travel. The use of pallets also provides flexibility in distribution scale, both for small and large shipments, as well as utilizing appropriate vehicles to reduce the carbon footprint, especially if using renewable energy-based vehicles such as electric or hydrogen. With the right approach, distributing hydrogen using pallets can be a safe, efficient, and environmentally friendly solution in the clean energy ecosystem [7].

To ensure efficient logistics in the distribution of hydrogen and the operation of PEMFC, several factors need to be considered:

1) On-site storage: The amount of hydrogen that can be stored at the destination location must be adjusted to the energy demand. Insufficient storage will require more frequent shipping, which increases costs and carbon footprint.
2) Route efficiency: Route optimization is essential for minimizing mileage, energy consumption, and delivery time. The use of technology such as GPS and AI-based logistics management systems can help in determining the most efficient routes based on traffic conditions, distance, and delivery needs.
3) Delivery arrangements: Consider whether distribution can be done in large batch shipments to reduce shipping frequency and improve logistics efficiency.

Logistics and distribution route optimization can use mathematical model approaches such as Vehicle Routing Problem (VRP), which considers distance, vehicle capacity, and user demand. It also considers environmental variables such as traffic conditions and fuel or energy efficiency. It aims to minimize mileage, delivery time, and energy consumption, thereby improving overall distribution

efficiency. Taking all these factors into account, the efficient distribution of hydrogen and the use of PEMFCs can be optimized to minimize costs and carbon footprints, as well as improve logistics efficiency.

## 3. Methodology

Levelized cost of electricity (LCOE) is a primary metric used to analyse the cost of various power generation technologies [8]. In the LCOE calculation designed, 2024 is used as the starting point for the simulation of the use of PEMFC as a Hydrogen Generator (GEH2) and Diesel Generator that lasts until 2060, with an analysis interval of every ten years. Technical assumptions are used in estimating annual energy production per type of back-up power supply technology. Parameters such as learning rate will affect fluctuations in the investment cost of the power plant project throughout the observed period. These technical assumptions, including constant engine efficiency and a stable learning rate, are assumed to remain unchanged over the operational duration of the plant. Data on capacity, efficiency, lifetime, and learning rate are obtained based on references while the exciting capacity of data is from references.

## 4. Finding dan Discussion

### 4.1. Operational Cost of Backing Up Power Supply

In calculating the operational cost of backing up power supply using the least cost method, a series of financial assumptions are considered that contribute to the annual value of the plant. The assumption of the initial cost of investment (CAPEX), which is annualized using a 10% discount rate over the life of the project, as well as the degradation of the CAPEX value affected by the projected generation capacity based on the technology until 2060 and the rate of learning of the technology in question, are key parameters in the LCOE calculation [9].

Table 1. Technical Assumptions of GEH2 Technology and Diesel Generator Sets in Indonesia

| No | Plant Technology | Technical Assumption | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | Capacity (MW) | Efficiency (%) | CF inc Outage (%) | Life Time (year) | Carbon Emission Factor kgCO2eq/kWh | Learning Rate (%) | Learning Index (b) | Capacity Existing (MW) | Annual (kWh) |
| 1 | GEH2 100 KW GENSET | 0.1 | 50 | 95 | 30 | 0 | 27 | 0.0039 | 0.1 | 416,100 |
| 2 | DIESEL 100 KVA | 0.1 | 46 | 95 | 25 | 1.098 | 1 | 0.0001 | 1 | 382,812 |

In addition to considering the initial cost of capital or CAPEX, the model also incorporates (O&M) back up power supply, which is expected to decline in line with increased expertise and efficiency through a continuous learning rate of the technology. It also considers the effect of annual inflation of 1-2% which will be measured in USD/kW.

Table 2. GEH2 Mobile Equipment Price Reference

| CAPEX | [ $ ] | Unit | REF |
|---|---|---|---|
| Hydrogen Power Generator 100 kW | 350.000 | $ | [10] |
| Compressed Tank 350 Bar 150 Bottle @720 Euro/kg | 120.000 | $ | [11] |
| **OPEX** | **[ $ ]** | **Unit** | **REF** |
| Fixed OM | 24 | $/kW | [12] |
| Truck Rent | 9.150 | $/year | [13] |
| **Fuel Cost** | **[ $ ]** | **Unit** | **REF** |
| Green Hydrogen | 6 | $/kg | [14] |

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The variable additional cost that is calculated is the fuel cost. This cost is estimated based on the projected price of fuel from external sources for the period 2023 to 2060, in USD/kWh. This fuel cost will be annualized based on the estimated annual energy generation and production capacity, which results in the following annual cost values as show in Table 2, Table 3 and Table 4.

Table 3. Diesel Generator Price Reference

| Component | [ $ ] | Unit | REF |
|---|---|---|---|
| CAPEX; Genset Diesel | 29.000 | $ | [15] |
| OPEX; Fixed OM | 8 | $/kW | [16] |
| Fuel Cost; Diesel | 0,21 | $/kWh | [17] |

Table 4. Projected Fuel Prices Until 2060

| No | Source | Variable Cost Total USD/kWh | | |
|---|---|---|---|---|
| | | 2020 | 2030 | 2060 |
| 1 | Green Hydrogen | 0,3850 | 0,2200 | 0,0917 |
| 2 | Diesel | 0,21 | 0,25 | 0,31 |

Table 5. Technical Assumptions of FC Technology and Diesel Generator Sets in Indonesia

| No | Plant Technology | Financial Assumption | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Fuel Cost (USD) | | | | | CAPEX ($/kW) | | | | | Biaya O&M ($/kW) | | | | |
| | | 2020 | 2030 | 2040 | 2050 | 2060 | 2020 | 2030 | 2040 | 2050 | 2060 | 2020 | 2030 | 2040 | 2050 | 2060 |
| 1 | GEH2 100 KW | 160,199 | 91,542 | 53,400 | 45,771 | 38,143 | 3,500 | 3,500 | 3,500 | 3,455 | 3,432 | 23.90 | 22.95 | 22.50 | 22.05 | 21.61 |
| 2 | GENSET DIESEL 100 KVA | 78,579 | 95,236 | 103,257 | 111,279 | 119,301 | 290 | 290 | 290 | 290 | 290 | 8.00 | 8.00 | 8.00 | 8.00 | 8.00 |

Proton Exchange Membrane Fuel Cell (PEMFC) is a technology that is increasingly in demand as a clean and environmentally friendly energy solution. This system works by utilizing hydrogen as a fuel to generate electricity through electrochemical reactions. During global efforts to switch to renewable energy, it is important to analyse the economic potential of PEMFC, one of which is through the measurement of Levelized Cost of Energy (LCOE). LCOE is a metric used to determine the average cost of energy production over the life of a project, considering the initial investment, operating costs, fuel, as well as the operating life of the system. The following is the LCOE calculation formula that we use [9]:

$$LCOE_{Annuitizing} = \frac{\text{Annual (Cost)}}{\text{Annual (Output)}} = \frac{\text{(Annual CAPEX + Annual OPEX + Annual Fuel (Cost)}}{\text{Annual Output}} \quad (1)$$

The initial investment (CAPEX) in the PEMFC Mobile system includes the cost of purchasing 1 set of Hydrogen Power Generator [10] and supporting infrastructure such as compressed hydrogen tanks [11]. One of the main challenges in the implementation of PEMFC technology is the relatively high cost of manufacturing and installation, especially related to the platinum components used as catalysts. Technology development and mass production are expected to reduce this CAPEX over time. In this paper, we use a discount rate of 10%.

Maintenance operational costs (OPEX) include routine maintenance, safety maintenance costs and hydrogen distribution costs from the hydrogen plant to the site. The fuel cost that we use in the use of PEMFC Mobile is that we use Green Hydrogen as the main fuel produced by nearby plants in the

Greater Jakarta area and its surroundings. The cost of Green Hydrogen fuel has a prediction of a significant price decrease in 2060 so that it can reduce fuel costs. After the identification of technical and financial assumptions, calculations are carried out according to the LCOE equation [9] above, the results of the calculation of LCOE PEMFC (GEH2) are compared to Diesel Generators. The following are the LCOE results of the two technologies.

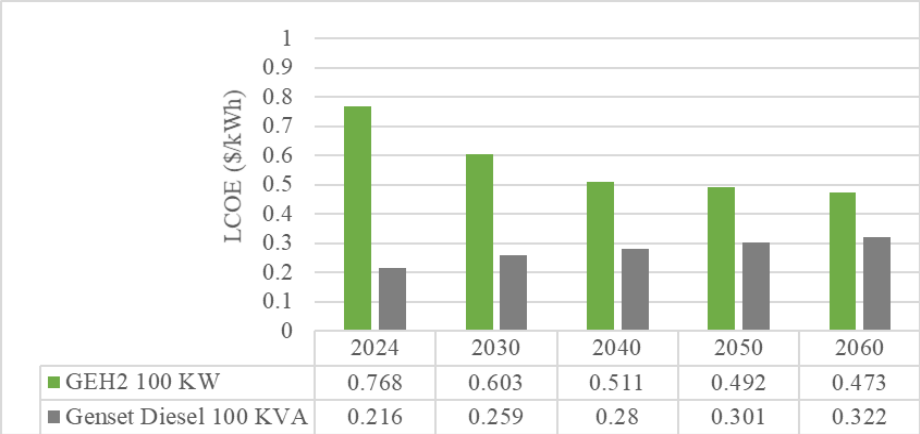


Figure 4. Comparison of GEH2 LCOE ($/kWh) with Diesel Generator Sets from 2024 to 2060

From the results of the LCOE calculation, the two types of back-up power supply can be seen that GEH2 has a very significant decrease in LCOE because it is influenced by a significant decrease in green hydrogen fuel prices from 2024 to 2060, in addition, the influence of a high learning rate of around 27% of GEH2 technology that contains fuel cells as a conversion from hydrogen to electrical energy is the cause of the decrease in LCOE from GEH2 then for diesel generators there is an increase LCOE is quite significant because it is influenced by the projected diesel price which will increase from 2024 to 2060.

### 4.2. Comparison of Grey Hydrogen, Blue Hydrogen and Green Hydrogen Carbon Emissions

Grey hydrogen is produced from fossil fuels such as natural gas through a process known as Steam Methane Reforming (SMR). In this method, natural gas (methane) is heated together with water vapor to produce hydrogen and carbon dioxide ($CO_2$) as by-products. Gray hydrogen is the most used form of hydrogen today, but its $CO_2$ emissions are very high, about 9-12 kg of $CO_2$ per kilogram of hydrogen produced. Since there is no attempt to capture its emissions, grey hydrogen makes a major contribution to greenhouse gas emissions [18].

Blue hydrogen is produced using the same method as grey hydrogen, but is equipped with Carbon Capture, Utilization, and Storage (CCUS) technology that captures most (up to 90%) of the $CO_2$ emissions produced during the production process. The captured carbon is then stored underground or utilized in various industries. Although its $CO_2$ emissions are lower than that of grey hydrogen, blue hydrogen still has challenges in terms of methane leakage during the natural gas extraction process and the rudimentary carbon capture efficiency, so it is not completely carbon-free.

Green hydrogen is produced using water electrolysis, where water is broken down into hydrogen and oxygen using electrical energy derived entirely from renewable energy sources such as wind, solar, or hydropower. Green hydrogen is the most environmentally friendly option because it does not produce carbon emissions during the production process. However, the cost of producing green hydrogen is currently still higher than that of grey hydrogen and blue hydrogen, although in the future these costs are expected to decrease in line with the improvement of the efficiency of electrolysis technology and the decrease in the cost of renewable energy [18].

### 4.3. Risks of Hydrogen Management and Storage in the Form of Compressed Gas

Hydrogen Fuel Cells offer a promising alternative to backup power supplies, with advantages such as energy independence, no noise, and good durability. Fuel cells produce electricity without harmful emissions, making them a more environmentally friendly option. However, there are some challenges

that need to be overcome to drive wider adoption. The safety aspect is very important to consider due to the highly flammable nature of hydrogen, so it requires strict handling and storage protocols. Handling of hydrogen storage and management risks can be minimized by using high-quality materials and the right technology for hydrogen storage and distribution [19].

The storage of hydrogen in the form of compressed gas is a standard method commonly used in the industry today. Hydrogen is stored at a high pressure of 350 bar and a room temperature of 293 ◦K or 20 °C, with a gravimetric energy density of 5.7% and a volumetric energy density of 4.9 MJ/L. Although this method has a lower volumetric energy density compared to liquid hydrogen storage or other methods, compressed gas storage remains popular due to its ease of handling, safety, and the availability of mature technology [20]. The management and storage of hydrogen in the form of compressed gas has risks that need to be considered to ensure safety. Flammable and leak-prone hydrogen requires careful handling. One of the main risks is the leakage and diffusion of high-pressure hydrogen, which can trigger spontaneous combustion. In addition, hydrogen can cause embrittlement (cracking) in storage materials, accelerate deterioration, and increase the risk of structural failure. The use of high-pressure tanks must be specially designed to withstand the high pressure of hydrogen [21].

**1) Risk of Hydrogen Explosion, Leakage and Diffusion**

The risk of hydrogen explosion and leakage is one of the main concerns in the management and storage of hydrogen, especially in the form of compressed gas. Hydrogen has flammable properties and can leak easily due to its very small molecules. Hydrogen leakage can lead to the formation of gas clouds that if they encounter ignition sources, can result in hydrogen cloud explosions. Even without an ignition source, a high-pressure hydrogen leak can lead to spontaneous combustion and explosion. Additionally, hydrogen has a wide concentration range for combustion in the air, which makes it more dangerous compared to many other gases. As a fuel, hydrogen has many advantages, such as high calorific value, environmental friendliness and wide availability. The density of hydrogen is much lower than that of air (air density is 1,293 kg/m3 under standard conditions of 1 atmospheric pressure and 0 $^{0}$C). In this case, hydrogen diffuses upwards rapidly under the action of air buoyancy after leakage and is not easy to accumulate to form a combustible gas mixture, which is conducive to its safety. However, compared with natural gas, hydrogen has many harmful characteristics, such as easy leakage, low minimum ignition, wide flammability range in air. Due to these harmful attributes and high cost, large-scale hydrogen utilization is subject to certain rules [21].

Hydrogen diffusion in a hydrogen storage tank involves the movement of hydrogen through the tank material, which can be affected by various factors such as pressure, temperature, and the properties of the tank material itself. Hydrogen can diffuse through interstitials in a metal lattice, and the presence of hydrogen traps in the material can affect the diffusion rate [22]. There are several mitigation measures that can be taken to reduce the risk of explosion and leakage in the storage of hydrogen in the tank. First, using materials that are resistant to high pressure and corrosion to reduce the risk of material failure. Second, the installation of a hydrogen leak detection system is indispensable to immediately detect and deal with leaks before they reach dangerous concentrations. In addition, adequate ventilation in the storage area must be maintained to prevent the accumulation of hydrogen that could trigger an explosion. The use of safety devices, such as pressure relief valves and automatic fire extinguishing systems, is also important for dealing with emergency situations. Finally, provide safety training to personnel and implement standard operating procedures for safe hydrogen handling. These measures aim to ensure that hydrogen storage is carried out safely and risks can be minimized [23].

**2) Hydrogen Embrittlement**

Hydrogen embrittlement in pipes and storage vessels is a complex process in which hydrogen forms solid solutions, hydrides, molecular hydrogen and gaseous products (such as methane) with pipe metals or metal additives, which can weaken the boundary bonding force of metal grains, resulting in brittle fractures or microscopic cracks or holes due to decreased pipe plasticity. Ambient temperature, pipe strength level, deformation rate and microstructure can affect the occurrence of hydrogen expiration. There is a synergy between local plasticity-enhanced hydrogen and hydrogen-enhanced adhesion [22].

Hydrogen Embrittlement risk mitigation involves several important strategies, including the selection of the right material, such as using steel with a specific chemical composition or composite materials designed to resist hydrogen penetration. In addition, environmental control also plays an important role by reducing hydrogen pressure and maintaining hydrogen purity, interactions that can

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cause Hydrogen Embrittlement to be minimized. Good design and maintenance are also required, including designing tanks and pipes with Hydrogen Embrittlement risks in mind as well as conducting regular inspections and maintenance to detect and repair damage before it develops into a serious problem. Finally, conduct compatibility testing and evaluation to ensure that the materials and designs used can withstand the effects of Hydrogen Embrittlement. The implementation of these strategies can help reduce the risk of hydrogen embrittlement and improve safety in hydrogen storage and transportation [21].

**3) Hydrogen-Induced Cracking**

Hydrogen Induced Cracking (HIC) is a phenomenon in which hydrogen dissolved in steel causes the formation of cracks. This process occurs when hydrogen penetrates the microstructure of steel and causes the formation of microcracks that can develop into larger cracks, resulting in material failure. Hydrogen-induced cracking (HIC) is usually accompanied by stress corrosion cracking (SCC), which leads to pipeline failure. Due to the synergistic effect of hydrogen and pipeline pressure, cracking occurs in the steel and accelerates the serious phenomenon of hydrogen embrittlement [22].

The combination of HIC and SCC is often referred to as hydrogen-assisted corrosion cracking, where external stress, corrosive environment, and the presence of hydrogen work synergistically to accelerate material failure. These cracks can be intergranular or trans granular, depending on the steel's microstructure and environmental conditions, and tend to be more severe in high-strength steels or microstructures that are more susceptible to hydrogen embrittlement. The right material selection is a crucial step in ensuring the resistance of hydrogen storage tanks to hydrogen penetration. The steel used must have a microstructure that is able to minimize hydrogen diffusion and reduce the risk of cracking. Although hydrogen storage tanks are not typically exposed to corrosive environments such as oil and gas pipelines, environmental control is still important, particularly in preventing moisture or contamination that can increase the risk of Hydrogen Induced Cracking (HIC).

In addition, the design of the tank must consider the even distribution of tension to avoid stress concentrations that can trigger cracks, while processing techniques that reduce inclusions and microstructural defects also have a significant role. Finally, the application of effective monitoring techniques to detect the presence of hydrogen and cracks at an early stage is essential to ensure the integrity of the storage tank [22].

**4) Hydrogen Blistering**

Hydrogen blistering is a phenomenon in which bubbles form on the surface of the material due to the accumulation of hydrogen. Blistering is often found in conjunction with hydrogen-induced cracking (HIC) and can be a clear sign of HIC because blisters are often visible to the naked eye or through optical microscopes with low magnification. Blistering occurs when hydrogen accumulates beneath the surface of the material, creating an internal pressure high enough to form bubbles or blisters. This phenomenon is often affected by the deformation structure and the presence of large carbides, which can trigger the formation of blisters on blisters where large blisters are adorned by smaller blisters [24].

Nucleation and crack propagation in blistering and HIC have very similar mechanisms, so they are often considered to be the same phenomenon, with the main difference being the presence of surface lift visible in blistering. Factors such as material thickness, microstructure, and inclusion distribution can affect the tendency of blistering to occur. Hydrogen blistering mitigation in hydrogen storage tanks can be done by choosing the right material, namely a material that has high resistance to hydrogen penetration and sufficient thickness can reduce the risk of blistering. Thicker materials are generally more resistant to blistering because they are more effective in reducing hydrogen loss to the surface [24].

In addition, the desulfurization process can remove nucleation sites near the surface that can cause blistering, so the decrease in sulphur content helps to minimize the risk of blister formation. The full de-oxidation process is also important because it promotes the segregation of manganese sulphide inclusions in the middle of the material thickness, which can reduce the tendency of blistering on the surface.

The application of a coating that is resistant to hydrogen penetration serves as an additional barrier to avoid hydrogen accumulation under the surface of the material. By implementing these strategies, the risk of hydrogen blistering in storage tanks can be minimized, which in turn improves the safety and reliability of the storage system [24].

### 4.3. Business Model

To develop PEMFC's business as a Back Up Power Supply, the Sustainable Business Model Canvas (SBMC) developed by Osterwalder and Pigneur offers a comprehensive framework for formulating effective and innovative business strategies [25]. This model allows related entities to systematically explore and define various key aspects of the hydrogen utilization business with PEMFC, in the form of Value Prepositions, Customer Segments, Channels, Customer Relationships, Revenue Streams, Key Resources, Key Activities, Key Partners, Cost Structure. The Canvas business model application can help related entities in identifying specific customer segments that will benefit the most from the provision of clean energy such as PEMFC, such as renewable energy project developers who are looking for more environmentally friendly alternatives, as has been done by many previous studies with different objects [26] [27].

The adoption of the canvas business model by Osterwalder and Pigneur, related entities and other stakeholders, a structured framework to accelerate the adoption of fuel cell technology in Indonesia. By leveraging this model, relevant entities can formulate strategies that not only support business goals but also contribute to broader environmental and social goals, underscoring Indonesia's commitment to clean and sustainable energy.

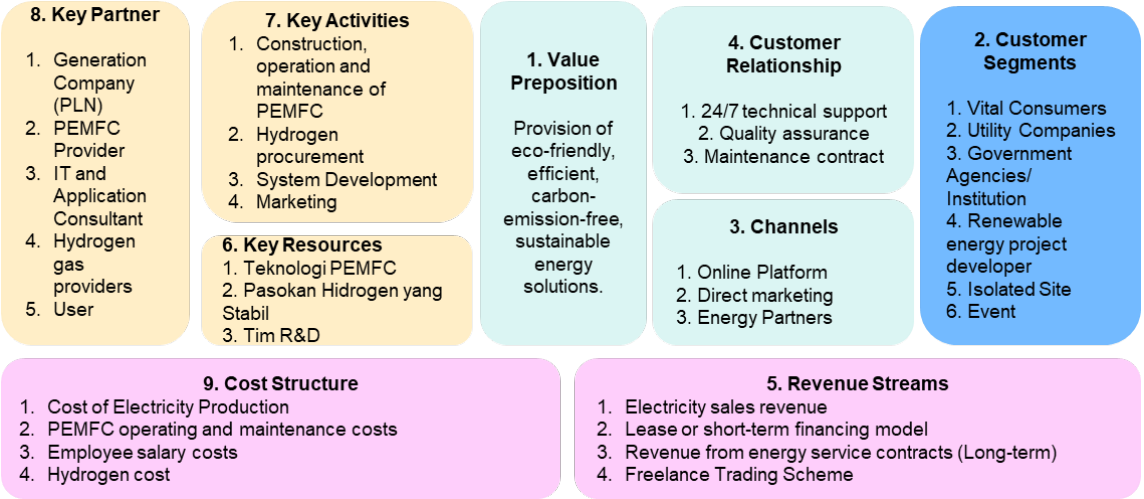


Figure 5. Sustainable Model Business Model of PEMFC Technology as a Mobile Generator and Back-Up Power Supply Environmentally Friendly

## 5. Conclusion

The potential of Hydrogen and PEMFC as power plants is recognized as an important source of renewable energy, which can be used as PEMFC fuel to produce electrical energy without carbon emissions. In this business strategy, there are 2 scenarios if associated with the source of electrical energy, namely excess hydrogen where the energy source is from PLTGU and PLTU, the second is Green Hydrogen where the source of hydrogen electrolysis energy is from hydropower plants, solar power plants and PLTP managed by PLN and IPP. This technology offers clean energy solutions that can be applied in various sectors, ranging from Temporary Service Products, namely Mobile Power Plants or indeed dedicated power plants which function only as a backup when the main source of electrical energy is disrupted. Infrastructure Challenges, although hydrogen and PEMFC technologies have great potential, their widespread adoption faces challenges such as high hydrogen production, storage, and distribution costs. Investments in infrastructure are needed for more efficient hydrogen storage and distribution systems.

Economic Benefits, the use of PEMFC as a backup power supply can reduce dependence on conventional energy, and potentially open new business opportunities in the sale and rental of hydrogen-based systems to consumers who care about clean energy. Sustainability and Carbon Emissions, the use of green hydrogen produced from renewable energy has the potential to

significantly reduce carbon emissions compared to grey or blue hydrogen. PEMFC technology supports global initiatives in reducing carbon emissions and improving energy sustainability.

The Implementation of the Sustainable Business Model Canvas (SBMC) helps in identifying the right market segments for this technology, as well as formulating business strategies that support the adoption of hydrogen and PEMFC technologies in Indonesia. A power plant has an excess hydrogen of 48.84 kg/day, which can generate 976.8 kWh or almost 1 MWh of electrical energy, then in Jabodetabek with 10 power plant locations, the potential electrical energy that can be mobilized using Fuel Cells is nearly 10 MWh per day.

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