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스마트시티용 고효율/친환경 에너지생산장치의 조건 분석

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Perspective: Analysis of Conditions for High-efficiency/Eco-friendly Energy Production Devices for Smart Cities

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요 약: 본 연구의 목적은 스마트시티 구축의 핵심인 수소연료전지의 활용형태를 분석하고 해결방안을 제시하는 것이다. 수소연료전지를 활용하는 발전소의 경우 간헐성 문제가 없다는 장점 때문에 향후 가장 유망한 사용 형태로 분석됐다. 다만 많은 장점에도 불구하고 폭발 우려와 특정 수소 생산방식의 경우 이산화탄소 발생 문제 등으로 지역주민들의 반발이 지속적으로 나타나고 있어 이를 해결하는 것이 스마트시티 구축의 주요 관건이 될 것으로 분석된다. 마지막으로 현재의 수소 생산방식을 분석하고 이에 따른 문제점을 파악하여 스마트시티의 완전한 구축을 위한 해결책을 제시하였다.

Abstract: The purpose of this study is to analyze the utilization forms of hydrogen fuel cells, which are the core of building a smart city, and suggest ways to solve them. In the case of power plants to utilize hydrogen fuel cell, it was analyzed as the most promising form of use in the future due to the advantage of being free from intermittence problems. However, despite many advantages, local residents' opposition continues to emerge due to concerns about explosions and the problem of carbon dioxide generation in the case of certain hydrogen production methods, and it is analyzed that resolving them will be the main key to establishing the smart city. Finally, by analyzing the current hydrogen production method and identifying the problems facing it, the solution for the complete construction of the smart city was presented.

Keywords: *hydrogen fuel cells, smart city, power distribution*

1. Introduction

With the global warming, the standard climate change have been serious problem. by carbon economy. Furthermore, the transition to the 'hydrogen economy' has been interested to achieve energy independence, not a necessary condition for solving environmental problems[1]. In particular, in the case of Republic of Korea, which relies on foreign sources for 99% of oil, coal, and natural gas, if the hydrogen economy is successfully realized, it is evaluated that the domestic economy will be able to take a new leap forward by replacing a significant part of energy with domestic production.

In terms of energy supply, the 'carbon economy' requires large-scale investments such as thermal power plants, and there are many restrictions in securing facilities/investment/space. Therefore, there is a great advantage that energy supply is relatively easy[2-5].

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In addition, in the case of thermal power plants that emit large amounts of fine-dusts and the nuclear power plants that have fears of explosions and problems with waste disposal, residents' acceptance is very low, despite the possibility of low-cost electricity production. However, in the case of hydrogen fuel cell power plants, which are evaluated as a major axis of the hydrogen economy, there are relatively few restrictions on location compared to thermal power plants and nuclear power plants, and they have a great advantage in expanding installation due to their high acceptance by residents. In the case of thermal power plants that emit a large amount of carbon dioxide, the main cause of greenhouse gases, there is high possibility that they will be removed from the energy market within the next 10 years, but in the case of hydrogen fuel cell power plants, there is no greenhouse gas emission and pollution such as fine-dusts. Therefore, the transition to the 'hydrogen economy' can be evaluated as an inevitable global trend[6-12].

In addition, since there are many technological areas in which Korea has an advantage in terms of core science and technology for building a hydrogen economy, the economic ripple effects such as improving trade-balance through exports and creating jobs for the hydrogen industry are expected to be large when a hydrogen economy is globally established.

Therefore, through this study, we will analyze the utilization form of hydrogen fuel cell, which is the core of building a hydrogen economy, and identify the challenges for each form. Furthermore, we suggest the problems to be solved for the complete construction of the hydrogen economy and suggest solutions to solve them.

2. Discussion

A hydrogen fuel cell is a device to convert the chemical energy of hydrogen (H_2) and oxygen (O_2) into electrical energy through an electrochemical reaction. The principle is that the hydrogen gas supplied to the anode is separated into hydrogen ions (H^+) and electrons (e^-) by platinum (Pt), and the generated hydrogen ions move to the cathode through the electrolyte. In the case of electrons, they move to the air electrode through an external circuit, and as a result, a current is generated. At the air electrode, hydrogen ions and electrons passing through the electrolyte meet, and water (H_2O) is generated through a combination with oxygen. Since the product is only water (H_2O), it is evaluated as a representative eco-friendly renewable energy as shown in Table 1. In addition, since hydrogen can be produced from water (H_2O), an infinite resource, it is expected to be a future-oriented energy.

Table 1. Comparison: Fuel Cells and Conventional Methods

	Coal	Gas	Fuel Cell
Electrical efficiency	38~45%	~55%	42~60%
NOx generation (ppm)	50	20	0

In the case of electric vehicles (EVs) that are in competition, it takes 5~10 hours for normal charging and 1 hour for high-speed charging. On the other hand, in the case of a fuel cell electric vehicle, since it takes about 3 minutes for one charge at the present time, it has an advantage in terms of charging time.

In the case of charging infrastructure, there are about 100 hydrogen charging stations nationwide (April 2022), and the number of hydrogen vehicles supplied is 20,683 (April 2022). However, it was analyzed that the relative regional gap was larger that not only did 170 units per unit be handled, but only two locations were installed in Jeonnam and Gyeongbuk, respectively. Meanwhile, in the case of electric vehicle chargers, the number of installed units is rapidly increasing, and more than 70,000 units have already been in operation nationwide. Electric vehicles are showing an overwhelming advantage in terms of charging infrastructure. The slow installation speed of hydrogen gas stations is difficult to access only with investment from individual businesses without support from local governments, as the installation cost is about 3 billion won (as of 2021) when changing existing gas stations to hydrogen gas equipment.

In addition, with the rapid increase in the number of

electric vehicles supplied, existing gas stations are highly likely to be selected to switch to electric vehicle charging stations in terms of cost, and in the case of hydrogen gas stations, localization of various facilities/devices for storing hydrogen is progressing slowly. Thus, it is difficult to expect a rapid increase in hydrogen gas stations in a short period of time.

- In terms of price competitiveness, Hyundai Motor Company's Nexo models range from 67.65 to 70.35 million won (as of March 2022), and Tesla Model 3 has a similar price range, ranging from 53.69 to 73.69 million won, but has infrastructure weaknesses such as charging stations. It is expected that it will be difficult for hydrogen fuel cell vehicles to show significant growth potential if they do not have price competitiveness. The relatively high manufacturing cost of hydrogen fuel cell vehicles is due to platinum (Pt), which is essentially inserted into the fuel electrode. Specifically, it is used as a membrane electrode assembly (MEA) catalyst and an average of 30 to 50 g of platinum is required for one hydrogen vehicle, and it is analyzed that there is a limit to lowering the manufacturing cost of a hydrogen fuel cell due to the continuous increase in price. In order to replace platinum (Pt), which is essential for hydrogen fuel cells, several attempts have been suggested by industry, and research institutes around the world, and meaningful results have been achieved. However, it is still difficult to replace platinum in a short period of time in terms of stability and efficiency.

- In terms of safety, since the gas storage is mandatory in the case of hydrogen fuel cell vehicles, there are constant concerns about safety. Currently, the gas storage for hydrogen fuel cell vehicles is being released after various safety tests, and it is confirmed that safety is guaranteed even in extreme tests. However, it is analyzed that it is practically impossible to completely erase from consumers. When an actual hydrogen storage explodes, it exerts a power that is incomparable to that of an electric vehicle. Thus, developing technology to dispel concerns can be a continuous task for the industry.

2.1. Future prospects of hydrogen fuel cell power plants

- According to data from the Ministry of Trade, Industry and Energy in January 2022, the supply of fuel cells for homes and buildings has grown from 3,786kw in 2018 to 7,340kw in 2021, doubling in four years. In particular, the annual power generation of fuel cells for power generation in 2018 was 1742GWh (accounting for about 0.3% of total domestic power generation), and in 2020, it has grown significantly to 3480GWh (0.6% of power generation), and has been showing continuous growth since then, and in 2022 the share of power generation is expected to approach 1.3%. This rapid growth is attributable to that hydrogen fuel cells are free from the problem of intermittent power generation of renewable energy to require a separate energy storage device and has higher power generation efficiency than solar or wind power.

- As the government continues to expand the fuel cell market for power generation and aims to achieve 15GW by 2040, the future prospects of hydrogen fuel cell power plants are evaluated very positively.

2.2. Challenges facing the hydrogen fuel cell industry

2.2.1. Opposition phenomenon of local residents

- Contrary to the prospect that hydrogen energy is eco-friendly and future energy, the region opposes the attraction and construction of a hydrogen fuel cell power plant with citing various reasons. The representative reason for opposition is the safety of hydrogen energy, and even with a very low probability, concerns about a large-scale disaster that can occur in the event of a hydrogen gas explosion continue to be expressed.

- In addition, concerns about the hydrogen production method are continuously expressed, and the method of producing hydrogen by decomposing natural gas is currently a hot topic of discussion. The method of producing hydrogen by decomposing natural gas at high temperature/high pressure is a representative method to account for about 50% of production world-

wide, and carbon dioxide is generated in addition to hydrogen as a product. Since carbon dioxide, which is a product, is a major cause of global warming, local residents are constantly raising problems with the process method in which carbon dioxide, a threat to the environment, is simultaneously generated in the process of obtaining hydrogen.

2.2.2. Low-efficiency of hydrogen production

- Electrolysis is the method of producing hydrogen by applying electric energy to water. Since water (H_2O), which is evaluated as an infinite resource, is used as a raw material, there is no disadvantage of limiting raw materials, but there is a disadvantage of requiring another energy to produce hydrogen. Since the energy required has to depend on thermal power plants or nuclear power plants, despite a lot of research and development being done, it is evaluated as not a efficient method at the present time, and currently accounts for only about 4% of global hydrogen production.

- Microbial decomposition method is a method of producing hydrogen using specific microorganisms, Thermococcus onnurineus NA1 among various microorganisms is in the spotlight. This microorganism is a type of archaea and has the characteristics of growing at a temperature of 63 to 90 °C. It can produce hydrogen using various organic substances such as proteins and organic acids, as well as carbon monoxide and formic acid. However, it is difficult to change the existing facility system for hydrogen production within a short period of time since it is difficult to stably and continuously supply carbon monoxide, which is food for microorganisms in a large amount.

- By-product hydrogen is a method of separating only hydrogen from gas generated during the petrochemical process and steel plant process. In July 2020, the world's first and largest fuel cell power plant to utilize by-product hydrogen was completed in Daesan Industrial Complex in Seosan, Chungcheongnam-do, drawing great attention. However, it is analyzed that it is difficult to be supplied as large-scale since by-product hydrogen has a limited supply as it is produced as by-product in the process.

- Natural gas decomposition is a method to decompose natural gas at high temperature/high pressure, and carbon dioxide and water are generated as products. It is evaluated as the most common method since it is suitable for mass production in terms of process, accounting for 50% of the world's production. However, it is not evaluated as an eco-friendly method since it generates carbon dioxide, an environmental pollutant, as a product and requires a high-temperature/high-pressure process. In addition, since natural gas itself is an energy source, the method to require the consumption of existing energy to obtain hydrogen energy is difficult to be evaluated as a sustainable production method.

2.2.3. Condition for efficient power distribution and energy-saving devices

Since energy is essential for hydrogen production, as energy costs increase, the cost of electricity production of hydrogen fuel cell power plants tends to increase as well. Therefore, it is judged that a separate energy storage device is essential in order to stably supply electricity through a hydrogen fuel cell power plant without an increase in electricity rates. Therefore, when the cost of hydrogen production is expected to increase, if electricity is stored in an energy storage device such as a battery in advance through a hydrogen fuel cell, a relatively stable electricity supply is expected to be possible. In order to prepare for the above situation, more detailed research is needed on the power capacity, number, and installation conditions of energy storage devices in the future.

2.2.4. Development of high efficient membrane for fuel cell

In order to develop a high-efficiency fuel cell, it is essential to develop a high-performance separator, especially high hydrogen ion conductivity. In order to increase the hydrogen ion conductivity, the mobility of the polymer used must be high, and various attempts have been made for this purpose. In particular, many

studies have been conducted to increase the hydrogen ion conductivity by using low molecular weight polymers, applying polymer materials with low rotation energy, or using various additives. If a polymer separator for hydrogen fuel cells is continuously developed and higher performance is secured than before, the popularization of hydrogen fuel cell power plants is expected to be accelerated.

Furthermore, the volume expansion of the electrolyte membrane generated during operation of fuel cell and the resulting crossover of hydrogen gas are considered as the main factors to reduce the performance and durability. The crossover is a phenomenon in which hydrogen gas passes through the electrolyte membrane and moves to the opposite electrode. Unfortunately, if the membrane is damaged due to repeated expansion, the crossover of hydrogen gas would be generated, resulting in the decrease of ion conductivity and the efficiency of fuel cell. Therefore, if stable membranes are developed independent of cross-over, power plants based on hydrogen fuel cell will be easily popularized.

3. Conclusion

Through this study, the utilization form of hydrogen fuel cells, which is the core of the hydrogen economy, was analyzed from the perspective of automobiles and power plants. Due to various concerns, it was analyzed that competitiveness was lower than that of electric cars. However, cargo trucks, which are relatively free from the location and number of charging stations, are analyzed to be competitive compared to electric vehicles. Technically, if the use of platinum catalyst is gradually reduced through the development of nanotechnology, It is expected that it will be competitive in terms of price.

In the case of hydrogen fuel cell power plants, the share rate of power generation is showing the rapid growth, approaching 1.3% in 2022, which is higher than solar or wind power generation since there is no the intermittency of renewable energy to require additional energy storage devices. Due to the advantage of being free from problems, it is analyzed as the form of use with the highest potential for future development. Furthermore, the phenomenon of refusal of residents is relatively smaller than that of thermal power plants and nuclear power plants. Therefore, it was analyzed that the process of dispelling the concerns of local residents by actively promoting eco-friendly factors that are superior to existing thermal power plants and nuclear power plants was analyzed as important factor.

Finally, by analyzing the current hydrogen production method and identifying the problems, the solutions for the complete construction of the hydrogen economy were presented. Representative methods include electrolysis, microbial decomposition, by-product hydrogen, and natural gas decomposition. In the case of electrolysis, there is a great advantage of using water, an infinite resource, as a raw material, but there is a disadvantage that separate energy is required for hydrogen production. Currently, it accounts for about 4% of global production, but it is expected that it will be difficult for the electrolysis production method to expand further in the future. In the case of the microbial decomposition method, a specific microorganism (Thermococcus onnurineus NA1) is in the spotlight as a method of producing hydrogen using proteins, organic acids, carbon monoxide, etc. However, it was expected that if this problem could be solved, it would account for a significant portion of hydrogen production.

In the case of by-product hydrogen, only hydrogen should be separated and used from gas generated during petrochemical processes and steel plant processes, and since it is produced as a secondary product in the process, the amounts of supply is limited. Thus, it was expected that it would be difficult to gradually increase its market share. In the case of natural gas decomposition, which accounts for 50% of the world's production, it is widely used since it is a production process suitable for mass production, but it generates carbon dioxide as a product and requires high temperature/high pressure as separate energy. Therefore, in

order to become a sustainable production method, if facilities capable of immediately capturing the generated carbon dioxide are installed/expanded in a low-cost structure, and process technology that can lower the temperature and pressure is continuously developed. However, since the stable implementation of the hydrogen economy is expected to be possible, it was analyzed that the government's policy support for the technology is desperately needed.

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