Taiwan–UK Cooperation in Hydrogen Industry

臺英氫能產業合作評估報告

Entrusting Agency：British Office Taipei

Executive Institute：Taiwan Institute of Economic Research

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Chapter I

Overview of Energy Development in Taiwan

Energy independence is an important indicator of national energy security. Taiwan's natural resources are limited, and most of its energy depends on foreign imports. According to the statistics of domestic energy supply and demand of the Bureau of Energy of the Ministry of Economic Affairs in 2020, Taiwan's self-produced energy is only 2.21%, and the imported energy is as high as 97.79% (as shown in Figure 1).

With the international expectation to jointly curb global warming and reduce greenhouse gas emissions, countries all over the world have put forward various carbon reduction strategies. Renewable energy has the clean characteristics of low environmental impact, which is widely recognized by most people. Meanwhile, it is also a solution to improve the energy self-sufficiency rate. Promoting the development of renewable energy in Taiwan is the future trend. The following is an overview of Taiwan's energy from the current situation and development trend of energy structure.

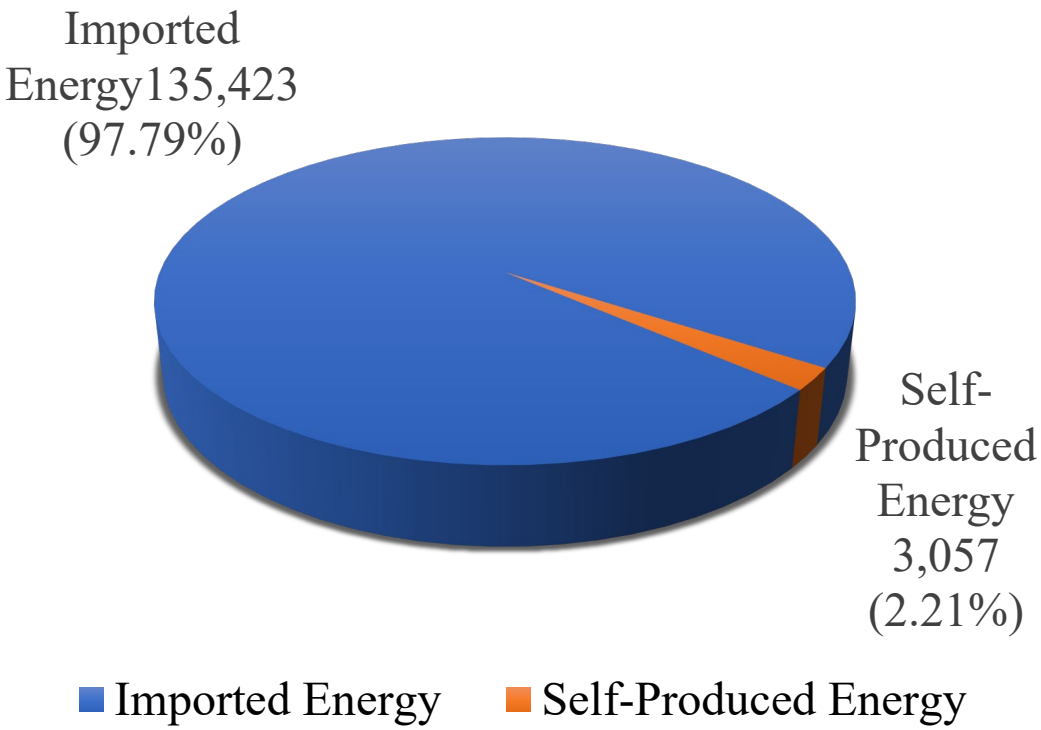

Figure 1. Overview of energy supply in 2020 (unit: kL)

Source: Bureau of Energy, drawing by TIER

1. Current Situation of Taiwan's Energy Structure

With the development of science and technology, Taiwan's electricity demand remains high (as shown in Figure 2). According to the energy statistics of the Bureau of Energy of the Ministry of Economic Affairs in 2020, Taiwan's power generation is divided in which coal accounts for 45.02%, fuel oil accounts for 1.52%, pumped storage hydropower accounts for 1.13%, renewable energy accounts for 5.4%, nuclear energy accounts for 11.24% and natural gas accounts for 35.7% (as shown in Figure 3).。

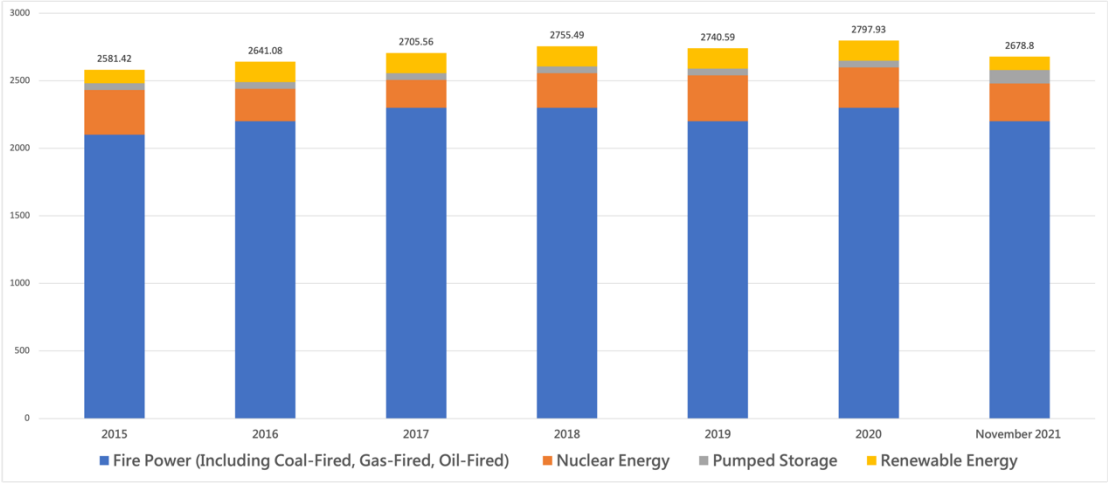

Figure 2. Cumulative power generation of each year from 2015-2021 (100 million kWh)

Source: Green Energy Industry Promotion Center, drawing by TIER

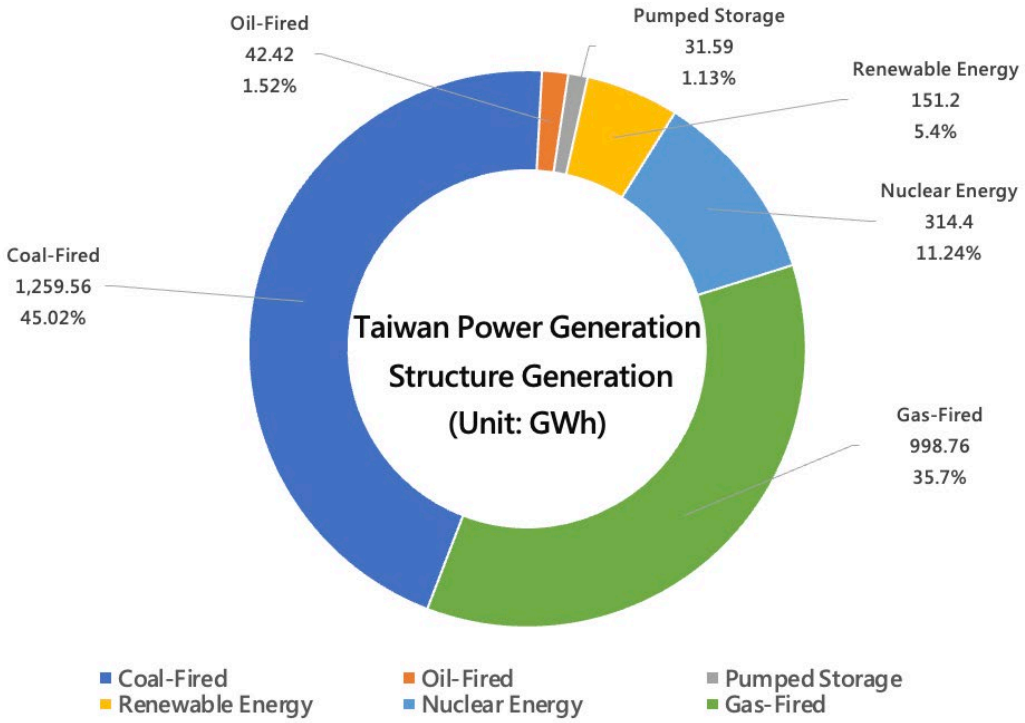

Figure 3. Power generation structure and capacity of Taiwan in 2020

Source: Bureau of Energy, drawing by TIER

The Legislative Yuan announced “Renewable Energy Development Regulations” in 2019, aiming to increase the capacity ratio of renewable energy power generation units by 20% and the unit capacity by 27 million kW by 2025. However, by the end of November 2021, Taiwan's total renewable energy unit capacity has only reached 11,120 MW (as shown in Figure 4), and the energy power generation structure accounts for only 5.4% (the total power generation capacity is 15.904 billion kWh).

In order to achieve the zero carbon target in 2050, the government still needs to actively promote measures, such as energy conservation, energy creation, energy storage and intelligent system integration, so as to completely transform the energy structure and drive the development of green energy industry.

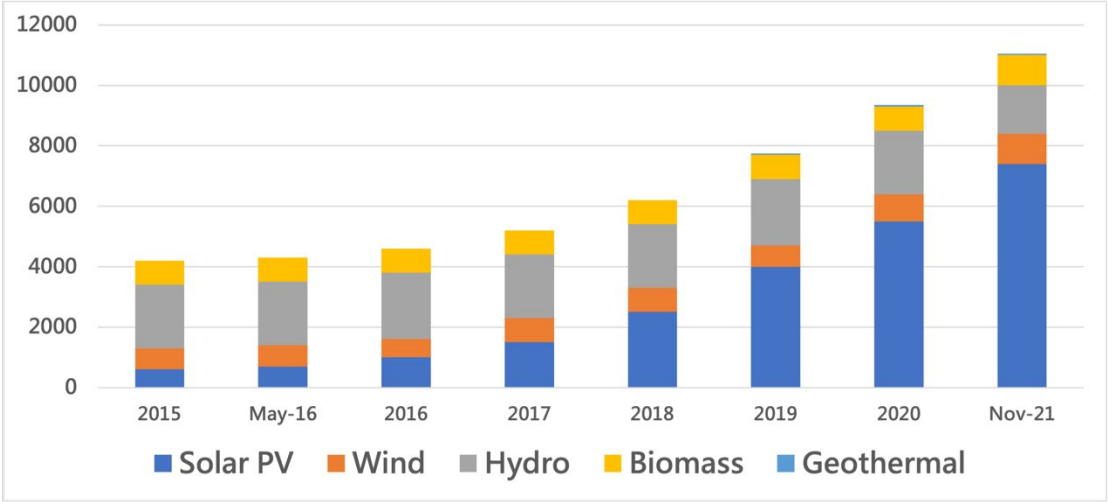

Figure 4. Capacity of renewable energy units from 2015 to November 2021

Source: Green Energy Industry Promotion Center, drawing by TIER

2. Taiwan Energy Development Trend

Energy is the pillar supporting the operation of social and economic system. Based on the consideration of different values and risk costs, the issue of energy ratio selection has been highly discussed by all sectors of society. In response to the challenges brought by global climate change and domestic air pollution, Taiwan put forward the energy transformation policy in 2016 and will develop the transformation path of low-carbon and clean energy, shape the new look of future power development and use, and create a new vision for the environment, economy and industry.

According to the 2020 White Paper on Energy Transformation of the Ministry of Economic Affairs, the goal of energy transformation in 2025 will be to achieve 20% of renewable energy power generation, and complete relevant energy infrastructure and supporting measures as scheduled, so as to ensure stable power supply, reduce pollution and decrease carbon emissions.

In order to achieve the above goal of energy transformation, the government continues to promote the rationalization of energy prices and the collection of relevant pollution control fees. In the evaluation process of policies and plans, the concept of external cost is gradually introduced to reflect the overall benefits of energy transformation policies. In addition, the government will further review fossil fuel subsidies, green tax system or other policy tools to reasonably and effectively reflect the internal and external costs of energy use, and implement the user payment principle and the polluter responsibility principle.

For Taiwan's energy planning, there are relevant measures for energy conservation, energy creation and energy storage. On the energy-saving path, the government plans to improve the energy intensity and power

intensity by an average of 2.4% and 2% from 2017 to 2025 respectively through technological breakthroughs and supporting measures.

In terms of energy creation, in order to improve the energy self-sufficiency rate and move towards the goal of net zero carbon emission, the government announced the implementation of the "Renewable Energy Development Regulations". The government regulates the total amount of incentives for renewable energy power generation equipment, and enables the steady and long-term development of renewable energy through clear objectives and relevant supporting measures. In addition, the government has actively developed clean energy, and the overall promotion is based on the five principles of "mature and feasible technology", "cost-benefit orientation", "phased and balanced development", "driving industrial development" and "acceptable impact of electricity price".

The government has planned the development goals of all kinds of clean energy. In 2025, the promotion objectives of various clean energy sources are solar photovoltaic 20,000 MW, wind power 6,938 MW, geothermal energy 200 MW, biomass energy 813 MW, hydropower 2,150 MW and fuel cell 60 MW, and achieve the goal of power generation accounting for 20%. The complete development strategies for all kinds of clean energy planning are as follows, with solar photovoltaic and offshore wind power as the main promotion projects.

- In terms of the promotion of solar photovoltaic power generation, "Two-Year Promotion Plan of Solar Photovoltaic Power Generation", "6.5 GW Compliance Plan in 2020" and "Ground-Based Project" are used to achieve the goal of solar photovoltaic setting a total of 20 GW in 2025.

- In terms of the promotion of wind power generation, through the "Four-Year Promotion Plan of Wind Power Generation", the land-based wind power and offshore wind power are planned respectively. Offshore wind power adopts the three-stage strategy of first demonstration, secondary potential area and later block area. The first offshore demonstration wind farm (128 MW) had been completed by the end of 2019. Taiwan expects that wind power generation will reach the target of 6.9 GW in 2025.
- In terms of the promotion of geothermal power generation, the primary goal at this stage is to promote "shallow geothermal energy" (traditional geothermal energy). Centralized and decentralized development are carried out in parallel, and it is expected to reach the target of 200 MW in 2025.
- In terms of the promotion of biomass energy, Taiwan hopes to reduce the cost of biomass fuel and improve the effective utilization of biomass energy by promoting high-efficiency biomass fuel conversion technology and application. In addition, Taiwan will continue to promote the installation of biogas power generation through demonstration awards, so as to achieve the goal of 813 MW in 2025.
- In terms of the promotion of hydropower, the short-term plan is to accelerate the development of hydropower projects by Taipower Corporation. In the medium and long-term plan, Taipower Corporation and private operators will work together to encourage small hydropower generation (less than 20 MW) and set a target of 215 MW by 2025.
- In terms of the promotion of fuel cells, the strategy is to develop stationary power systems and standby power systems. In addition, Taiwan will cooperate with the establishment of Shalun Energy Park to demonstrate the long-term operation of fuel cells, and set the policy

goal of realizing the capacity of fuel cell devices to reach 60 MW by 2025.

In terms of energy storage and smart system integration, energy storage equipment will be set up in cooperation with renewable energy to dispatch and stabilize the power generation and demand of renewable energy, provide electric system flexibility and standby capacity, as well as introduce regional energy storage and rolling review the energy storage demand. In addition, through the promotion of smart grid and smart electric meter, Taiwan will promote more effective TOU tariff and energy-saving measures. In the future, the government will continue to strengthen the implementation of energy transformation and renewable energy development strategies, technology research and development, guidance, subsidies and promotion, so as to promote the independent development of energy in Taiwan.

Chapter II

Overview of Hydrogen Energy Development in Taiwan

Hydrogen energy has the characteristics of diversified sources. Hydrogen fuel cell also has the advantages of energy storage, cleanliness and wide application fields. It can provide cleaner and effective alternatives to gasoline and other fossil fuels, and can also provide the required power for stationary type, transportation type, regional power grid backup and base load. It is the star of energy in the future. Unlike solar photovoltaic and wind power generation, which are limited by climate, hydrogen fuel cells can provide stable power supply only by continuously supplying fuel. Therefore, backup power and disaster prevention are particularly reliable and effective. Taiwan has been committed to promoting the development of hydrogen fuel cell industry for many years. The following will start from the policy and overall industry to analyze the specific policies for the development of hydrogen energy and fuel cell industry in Taiwan, as well as the current situation and development trend of hydrogen energy application.

1. Hydrogen Energy Policy

About 80% of the power generation structure of Taiwan's power system comes from fossil energy with high carbon emissions. In addition to causing air pollution, it is also the main source of greenhouse gas emissions. In this regard, the government has formulated a number of regulations and

subsidy policies to encourage all parties to develop renewable energy.

Considering that hydrogen energy will become one of the options for domestic energy supply, director You of the Bureau of Energy of Ministry of Economic Affairs also proposed on October 22, 2021: " Upon Taiwan's net zero carbon emission policy of energy transformation towards 2050, hydrogen energy is included in relevant carbon reduction plans, hoping to reduce carbon emissions from energy and industrial sectors. " In addition, the Ministry of economy has also established a hydrogen energy promotion group to expand the development and application of hydrogen energy. In the "2050 Net Zero Carbon Emissions Roadmap" published on 30 March 2022, it is proposed that a hydrogen energy management law will be promoted and future hydrogen power generation will be planned, which shows that hydrogen energy is given a very important role in the roadmap.

The following analyzes the current situation of Taiwan's hydrogen energy development policy from relevant laws and regulations as well as specific practices.

A. Relevant Laws and Regulations

■ Environmental Protection Agency (EPA)

a. Greenhouse Gas Reduction and Management Law

In July 2015, the Legislative Yuan passed ‘Greenhouse Gas Reduction and Management Law”, which clearly stipulates that the greenhouse gas emission in 2050 will be reduced to less than 50% in 2005. Taiwan had submitted INDC report, setting greenhouse gas emissions in 2030 as the current development trend (BAU) reduction of 50%, which is also equivalent to a further reduction of 20% compared with the emission level

in 2005.

b. Climate Change Response Law

In October 2021, the Environmental Protection Agency of the Executive Yuan announced the amendment of “Greenhouse Gas Reduction and Management Law”, which will fully update to “Climate Change Response Law”, including carbon fee, total emission amount control and other mechanisms, and amended to "zero net greenhouse gas emission in 2050".

■ Ministry of Economic Affairs (MOEA)

a. 2016 White Paper on Energy Industry Technology

"2016 White Paper on Energy Industry Technology" sets the policy goal of achieving a fuel cell device capacity of 60 MW by 2025. As of January 31, 2021, the total unit capacity of Taiwan's fuel cell power generation system had only reached 571 kW, which is still a certain distance from the policy goal. More policy measures are urgently needed to encourage private companies and people to build more fuel cell devices.

b. Amendments to the Electricity Act

The Legislative Yuan amended and promulgated the implementation of the Electricity Act on January 26, 2017. In accordance with Articles 9 and 10 of the act, the power transmission and distribution industry may charge fees for providing auxiliary services, power dispatching and power conversion services. In the future, green power operators can sell electricity

directly to users, so as to promote the liberalization of renewable energy power market.

c. Amendments to the Renewable Energy Development Regulations

The Legislative Yuan announced the amendment to the Renewable Energy Development Act in 2019, aiming to increase the capacity ratio of renewable energy power generation units by 20% and the unit capacity by 27 GW by 2025. In addition, large power users with a specified power contract of more than a certain capacity (5000 kW) should set up 10% green power, and enterprises are encouraged to set up renewable energy equipment by themselves.

B. Specific Practice

■ Ministry of Economic Affairs (MOEA)

a. Establish “National Renewable Energy Certificate Center”

The Ministry of Economic Affairs set up the "National Renewable Energy Certificate Center" in 2017 to concretize the environmental benefits of green power. Green power refers to solar photovoltaic power generation, wind power generation, green hydrogen fuel cell power generation, etc. The purchase of renewable energy certificates by enterprises can be regarded as a method of using renewable energy. By the end of 2021, more than 958,000 renewable energy certificates had been issued, with a trading volume of more than 816,000.

b. Formulate the "Subsidy Assignments for Stationary Fuel Cell

Power Generation System"

In recent years, Taiwan has put forward a number of energy transformation strategies. In response to this trend, the Bureau of Energy (BOE) of the Ministry of Economic Affairs proposed the "Subsidy Assignments for Stationary Fuel Cell Power Generation System" for the construction of stationary fuel cell power generation systems. For private companies, schools, medical institutions and other units, the government will subsidize the installation of fuel cells with a capacity of 1-500 kW. The maximum subsidy is NT $70,000 per kW to improve the willingness of relevant domestic units to build fuel cell power generation systems.

■ National Communications Commission (NCC)

a. Announce the subsidy of "Strengthening the Disaster Power Preparedness of Mobile Communication Base Station Plan"

For remote areas with inconvenient communication, fuel cell power generation system can be used as backup power. In case of earthquake and typhoon, the fuel cell will provide backup power for a certain number of hours for mobile phones. In November 2017, NCC approved the subsidy scheme of "Strengthening the Disaster Power Preparedness of Mobile Communication Base Station Plan ", and the subsidy objective was changed from the public sector to the telecommunications industry, so as to promote the establishment of emergency standby power for high disaster resistance communication platform of hydrogen fuel cell in Taiwan. As of May 2019, 11 cases of this subsidy have been completed. The list of cases is shown in Table 1。

Table 1. List of subsidy programs for "Strengthening Disaster Power Preparedness of Mobile Communication Base Stations Plan"

Year	No.	Location	Capacity	System Type
2019	1	Huafan University in New Taipei City	15 kW	Methanol Reformed Type
	2	Fangye Railway Station in Pingtung County	15 kW	Methanol Reformed Type
2018	3	Lala Mountain in Taoyuan County	15 kW	Methanol Reformed Type
	4	Taiwan Ocean University in Keelung City	20 kW	Methanol Reformed Type
	5	Sun Yat-Sen University in Kaohsiung City	22 kW	Pure Hydrogen Type
2017	6	Community Activities Center at Shuangchi District	20 kW	Methanol Reformed Type
	7	Community Activities Center at Sanxia District	20 kW	Methanol Reformed Type
	8	National Taitung University in Taitung County	26 kW	Pure Hydrogen Type
	9	Donghua University in Hualien County	20 kW	Methanol Reformed Type
2016	10	Union University in Miaoli county	26 kW	Pure Hydrogen Type
	11	Chung Cheng University in Chiayi City	25 kW	Pure Hydrogen Type
2015	12	Department of Sports, Taipei City Government	20 kW	Pure Hydrogen Type

Sources: NCC、TIER、THFCP

The relevant hydrogen energy policies can be shown as Table 2.

Table 2. Integration of relevant hydrogen energy policies

Item	Regulations	Authority	Time Period	Contents
Green Energy	Greenhouse Gas Reduction and Management Law	EPA	2015~ 2050	The greenhouse gas emission in 2050 will be reduced to less than 50% in 2005. Taiwan had submitted the INDC report, setting the greenhouse gas emissions in 2030 as the current development trend (BAU) reduction of 50%, which is also equivalent to a further reduction of 20% compared with the emission level in 2005.
	Climate Change Response Law	EPA	2021~ 2050	In October 2021, the Environmental Protection Agency of the Executive Yuan announced the amendment of “Greenhouse Gas Reduction and Management Law”, which will fully updated to “Climate Change Response Law”, including carbon fee, total emission amount control and other mechanisms, and amended to "zero net greenhouse gas emission in 2050".
	Amendments to the Electricity Act	MOEA	2017~	In accordance with Articles 9 and 10 of this act, the power transmission and distribution industry may charge fees for providing auxiliary services, power dispatching and power conversion services. In the future, green power operators can sell electricity directly to users, so as to promote the liberalization of renewable energy power market.
	Amendments to the Renewable Energy Development Regulations	MOEA	2019~	The objective is to increase the capacity ratio of renewable energy power generation units by 20% and the unit capacity by 27 GW by 2025. In addition, large power users with a specified power contract of more than

Item	Regulations	Authority	Time Period	Contents
				a certain capacity (5000 kW) should set up 10% green power, and enterprises are encouraged to set up renewable energy equipment by themselves.
	National Renewable Energy Certificate Center	MOEA	2017~	The objective is to concretize the environmental benefits of green power. Green power refers to solar photovoltaic, wind, green hydrogen fuel cell power generation, etc. The purchase of renewable energy certificates by enterprises can be regarded as a method of using renewable energy. By the end of 2021, more than 958,000 renewable energy certificates had been issued, with a trading volume of more than 816,000.
	2016 White Paper on Energy Industry Technology	BOE MOEA	2016~ 2025	The objective is to set the policy goal of achieving a fuel cell device capacity of 60 MW by 2025. As of January 31, 2021, the total unit capacity of Taiwan's fuel cell power generation system had only reached 571 kW, which is still a certain distance from the policy goal. More policy measures are urgently needed to encourage private companies and people to build more fuel cell devices.
Fuel Cell	Subsidy Assignments for Stationary Fuel Cell Power Generation System	BOE MOEA	2018~	For private companies, schools, medical institutions and other units, the government will subsidize the installation of fuel cells with a capacity of 1-500 kW. The maximum subsidy is NT $70,000 per kW to improve the willingness of relevant domestic units to build fuel cell power generation systems.

Item	Regulations	Authority	Time Period	Contents
	Strengthening the Disaster Power Preparedness of Mobile Communication Base Station Plan	NCC	2017~ 2019	For remote areas with inconvenient communication, fuel cell power generation system can be used as backup power. In case of earthquake and typhoon, the fuel cell will provide backup power for a certain number of hours for mobile phones. The subsidy objective was changed from the public sector to the telecommunications industry, so as to promote the establishment of emergency standby power for high disaster resistance communication platform of hydrogen fuel cell in Taiwan. As of May 2019, 11 cases of this subsidy have been completed.

Source：Sorting by TIER

At present, there are many achievements of fuel cell backup power systems all over the country (Fig. 5). The Bureau of Energy of the Ministry of Economic Affairs has invested more than NT $375 million in the Fuel Cell Demonstration and Verification Subsidy Assignment", and the manufacturers have invested NT $450 million by themselves. Since 2009, the actual operation cases of fuel cell generators have spread across at least 14 counties and cities in Taiwan, and more than 231 systems have been jointly built. In recent years, it has also begun to integrate fuel cell projects into transportation vehicles, smart grids and smart communities.

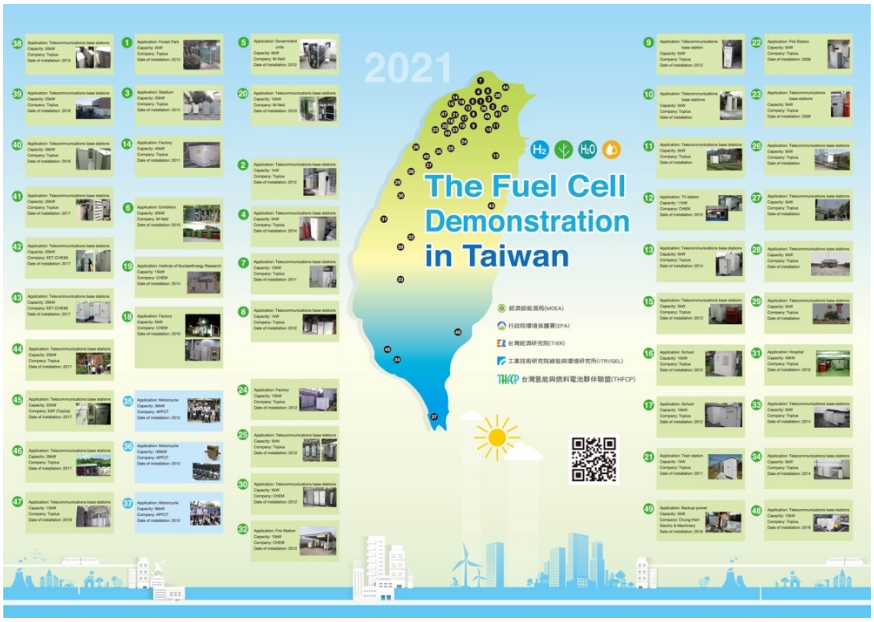

Figure 5. Overview of the operation of fuel cell field in Taiwan

Source: Taiwan Hydrogen Energy and Fuel Cell Partnership

2. Current Situation and Development Trend of Hydrogen Energy Application

As a clean energy carrier, hydrogen is an energy-saving and carbon reduction technology, which is vigorously developed in the world, including key topics such as hydrogen production, storage, transportation, power generation, heating, synthetic fuel and so on. The establishment of hydrogen energy industry and its rapid expansion depend on the comprehensive expansion of national strategic hydrogen infrastructure. Hydrogen production from existing petrochemical source, combined with carbon capture, storage and utilization technology, will eventually be converted to renewable energy for hydrogen production, and various hydrogen energy applications will be accelerated to replace the use of existing high-carbon energy.

At present, Taiwan's hydrogen source is mainly supplied by the three major domestic gas suppliers (Linde Lienhwa Industrial Gases Co., Air Products San Fu Co. and Air Liquide Far Eastern Co.), with a total hydrogen supply of about 10,296 tons per year. More hydrogen supply is still needed in the future. In order to achieve the goal of 2050 net zero carbon emission, the potential scale and situation of hydrogen supply and demand are evaluated respectively, and then the current situation and development trend of hydrogen energy application in Taiwan are also analyzed.

A. Assessment of Potential Scale of Hydrogen Supply

The global hydrogen production can be divided into gray hydrogen, blue hydrogen and green hydrogen. Grey hydrogen refers to hydrogen produced from coal, natural gas or other non-renewable energy, which will produce a large number of greenhouse gases, such as methane and carbon dioxide. At present, most of the hydrogen used in the world belongs to gray hydrogen, and the main hydrogen suppliers in Taiwan also provide gray hydrogen. Blue hydrogen refers to the hydrogen produced by carbon capture, utilization and storage (CCUS) in the traditional hydrogen production process. Blue hydrogen is considered to be a transition product from gray hydrogen to green hydrogen in the development of hydrogen energy. However, carbon capture technology cannot be fully captured and stored for a long time. Carbon storage must be adopted after environmental assessment, so it has certain geographical conditions.

Green hydrogen is defined as hydrogen produced by water electrolysis with renewable energy, including solar energy, wind power, hydraulic power, etc. At present, the global green energy supply cannot be used for

hydrogen production on a large scale, and only some demonstration sites have green hydrogen supply. Finally, another special way of hydrogen production is industrial residual hydrogen recovery, which refers to the recovery of hydrogen produced after industrial process, and belongs to a part of circular economy. Therefore, this kind of hydrogen is classified as green hydrogen in this report. The following will assess the future supply of blue hydrogen and green hydrogen in Taiwan under the goal of net zero carbon emission in 2050.

In terms of blue hydrogen, Taiwan's current supply is less, because the introduction of CCUS technology and the location of carbon storage field have yet to be solved. CCUS technology has reached a mature stage of development in the world. If the carbon capture device is installed in the SMR process stage, the carbon capture efficiency can be as high as 85 ~ 95%. However, carbon storage is only suitable for countries with large area, sparse population and stable stratum. According to the current environmental assessment of carbon storage in Taiwan, the sedimentary rock or deep saline layer in Western Taiwan is the most suitable area for carbon storage.

According to the geological survey, the current storage capacity in Taiwan is about 4 ~ 6 billion tons. However, Taiwan's potential recoverable carbon reserves are about 15 billion tons, so these areas are far from the sealable capacity of Taiwan. In addition, Taiwan is located at the junction of plate activity, and the stratum is more unstable than other areas. The rock strata in many areas are not completely horizontal, but have a certain inclination, resulting in gaps happened in the sealing layer. If the stratum changes after storing, it is very likely to lead to the leakage of carbon storage, which will pollute the water source or release high concentration carbon dioxide, and may pose a considerable threat to the lives or property of nearby residents.

Referring to the carbon storage technology adopted by European and American countries as examples, the carbon storage areas of the United States and Canada are located in the central and western regions, with little stratigraphic activity and at least 100 kilometers away from densely populated areas. Taiwan is at a disadvantage in terms of geographical environment. In addition to being located at the junction of plates, high population density is also a common living phenomenon. In addition, when selecting storage sites, the wishes and the support of nearby residents need to be considered at the same time. The relative coordination cost of nearby residents in Taiwan is relative high.

Choosing to import blue hydrogen from abroad can be an option. Taiwan's natural gas mainly depends on import, and carries out natural gas reforming to produce hydrogen. Therefore, it may encounter technical and mass production difficulties to develop blue hydrogen by itself. As one of the world's top blue hydrogen exporters, Australia and the United States may provide Taiwan with cheap blue hydrogen, so that Taiwan has buffer space between gray hydrogen and green hydrogen conversion and reduce carbon emissions in time.

Exporting carbon captured by CCUS abroad may also be another option. There is a Kasawari CCS project in Malaysia, which will carry out carbon filling at depleted coastal oil fields. According to the consultant's plan, about 7.6 million tons of carbon can be filled by the end of 2025.

Due to unavoidable geographical factors and the problem of construction cost, blue hydrogen is not suitable for Taiwan's hydrogen production target. It is suggested to develop blue hydrogen in the two directions of import and carbon export.

In terms of green hydrogen, the main reasons why it cannot be popularized quickly at present are cost control and the scale is not yet mature. For example, only 0.3 GW of electrolytic equipment for green

hydrogen production in the world will be completed by the end of 2020, and it is predicted that about 80 GW of electrolytic equipment will be completed by the end of 2030. If this large-scale equipment construction can be completed, the production cost of green hydrogen may be reduced.

According to the IEA 2021 report, the global hydrogen production is estimated as shown in Figure 6. Before 2030, it is still dominated by hydrogen production from fossil fuels. There will be large-scale green hydrogen production in 2030, and the green hydrogen production will reach about 300 million tons in 2050.

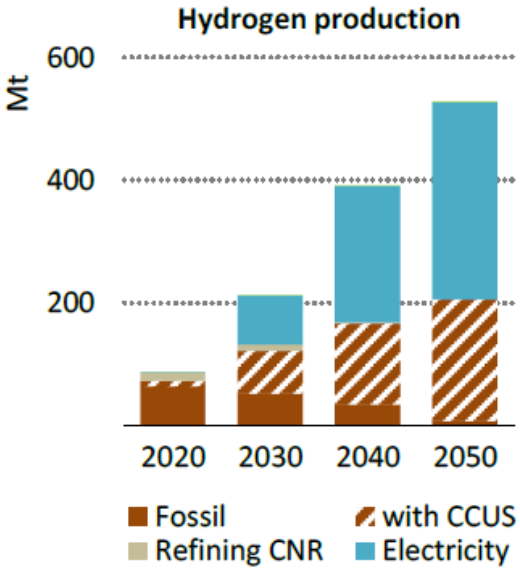

Figure 6. IEA estimations of global hydrogen production according to the demand from 2020 to 2050

Source: IEA

For example, Japan is an advanced country in hydrogen energy development. In 2020, about 20.8% of the country's total power generation came from renewable energy, and no effort will be spared in investing in hydrogen energy development. The investment of large-scale hydrogen supply chain is about US $2.7 billion, and about US $700 million is invested in green hydrogen production. If pure green energy is to be used

to produce hydrogen, sufficient renewable energy units are required. At present, the technology of hydrogen production adopted in Japan is still mostly the use of fossil fuels (coal and natural gas). The production of green hydrogen is in the situation of insufficient production capacity and high cost.

In all fields in Japan for producing hydrogen, only Fukushima Hydrogen Energy Research Institute uses 10 MW electrolytic cell to produce green hydrogen. The electrolytic cell used in this institute produces about 1200 Nm^3 of hydrogen per hour, which is equivalent to about 108 kg in terms of bulk density. It is estimated that it needs to consume about 4,212 kWh (1 kg of hydrogen can be produced by 39 kWh.) Based on the annual average of 8 working hours per day, and the annual operation time is 2,920 hours, 12.29 million kWh of renewable energy power is used every year to produce green hydrogen by water electrolysis. This power consumption is 0.057% of Japan's total renewable energy power generation in 2020, while Japan estimates that about 50 - 60% of the national power generation in 2050 will come from renewable energy, so about 0.2% of green electricity may be used to produce green hydrogen.

Taiwan's total renewable energy power generation in 2020 is 15.12 billion kWh (energy ratio is 5.4%), and the total renewable energy power generation from January to November 2021 is 15.904 billion kWh (energy ratio is 5.94%). Therefore, due to the limited proportion of renewable energy in Taiwan, it is estimated that there will be no large-scale green hydrogen production before 2030. As for the import part, it needs to be determined according to international supply market, domestic hydrogen demand and complete schedule of relevant transmission and storage infrastructure.

According to the energy proportion of three scenarios in 2050 estimated by the Ministry of Economic Affairs (see Table 3). Scenario 1:

45% of renewable energy, 32% of nature gas, 3.9% of nature gas with CCUs, and 18% of coal; Scenario 2 is the proportion of energy after coal is no longer used; Scenario 3 is mainly the energy proportion after reducing the proportion of nature gas. After the proportion of renewable energy is increased in the future, Taiwan will have the opportunity to refer to Japan's hydrogen energy supply situation and build a green hydrogen supply chain to produce green hydrogen on a large scale according to Japan's green power consumption ratio of 0.2% in 2050.

Table 3. Scenario of energy proportion in 2050 planned by the Ministry of Economic Affairs

Situation	Proportion of Energy
Scenario 1	renewable energy 45%, gas 32%, gas (CCUs) 3.9%, coal 18%
Scenario 2	renewable energy 46%, gas 39%, gas (CCUs) 13%
Scenario 3	renewable energy 80%, gas 10%, gas (CCUs) 8%

Source：Sorting by TIER

Based on the total power generation of 279.8 billion kWh in 2020, the increase rate in 2050 is estimated to be 30%, so the total power generation is 363.7 billion kWh. Referring to Taiwan's plan for the proportion of renewable energy, it is expected to reach 45 ~ 80% of the country's total power generation in 2050. According to the estimation of this study, Taiwan's renewable energy power generation will be about 163.7 ~ 291 billion kWh at that time. Referring to the proportion of green hydrogen in the total power generation of green energy in Japan, Taiwan can supply

about 8,394 ~ 14,924 tons of green hydrogen every year. According to the existing green energy power generation capacity in Taiwan, it is capable of meeting this standard. However, it must be carefully evaluated by considering the power grid configuration, power generation capacity, and power consumption.

Industrial residual hydrogen is also an option for Taiwan with the potential to develop green hydrogen. Taiwan's manufacturing industry is well developed. However, when manufacturing products, it will also produce a large number of chemical by-products, and hydrogen is one of them. For example, Chung Hwa Pulp Corporation produces an average of 1.23 metric tons of by-product hydrogen per day, and about 449 metric tons of hydrogen per year. In the process of silicon wafer cutting, Solar Applied Materials Technology Corporation produces about 548 metric tons of by-product hydrogen every year. Large factories in each industrial park also have a large amount of industrial residual hydrogen. If by-product hydrogen can be recovered, purified and utilized, this report believes that it will be of great long-term help to the development of green hydrogen.

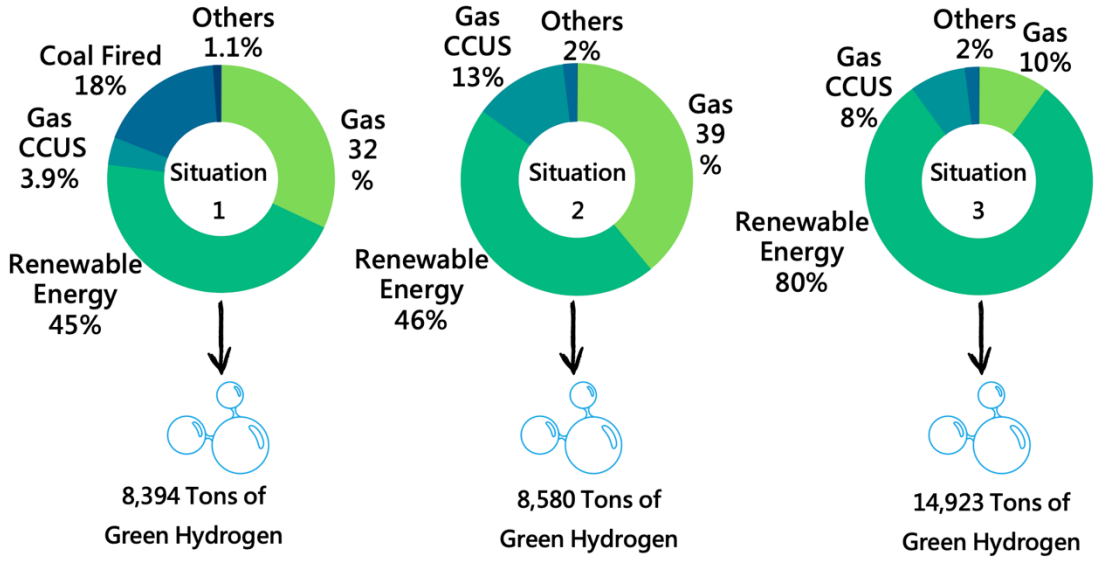

Figure 7. Estimated proportion of renewable energy in total power generation and green hydrogen production in Taiwan in 2050

Sources: Commercial Times, drawing by TIER

B. Potential Scale Assessment of Hydrogen Demand

Taiwan's hydrogen demand is affected by the government's R & D plan related to hydrogen energy and fuel cells, and is gradually increasing. According to the "2016 White Paper on Energy Industry Technology", Taiwan's key development goals in the hydrogen energy industry focus on the research and development of hydrogen fuel production technology, hydrogen fuel supply technology and proton exchange membrane fuel cell technology, which shows that Taiwan has a strong intention to expand the supply and demand of hydrogen energy.

In order to evaluate the potential demand scale of hydrogen in Taiwan, this study will preliminarily estimate the potential demand scale of hydrogen from current small hydrogen vehicles and energy storage systems of some telecom base stations, and then estimate the more specific hydrogen demand by referring to the estimated demand of Japan and South Korea.

Hydrogen demand can be divided into several uses: (1) stationary power generation/energy storage system, (2) transportation fuel, (3) large-scale power generation, (4) industrial processing, and (5) portable equipment. The stationary power generation/storage system is mainly used to provide backup power for some electric fields (factories, homes) or telecom base stations. It is also a very important link to promote Taiwan's smart grid in the future.

The part of fuel transportation is for hydrogen energy vehicles, such as hydrogen buses, scooters, locomotives, ships, etc. According to the requirements of different vehicles, the fuel cell capacity and hydrogen storage equipment are different. Large scale hydrogen power generation uses hydrogen combustion to promote the generator to generate electricity,

which can greatly reduce greenhouse gas emissions. In the industrial processing part, some processes need to use hydrogen for subsequent processing. Portable equipment is suitable for multi-functional purposes such as disaster relief and camping, just as portable small generators provide users with power.

At present, the main and most potential hydrogen demand in the world are stationary power generation/energy storage systems and transportation vehicles. At present, no power plant using pure hydrogen fuel has been put into operation, mainly because of the high cost of power generation and the problem of power generation efficiency.

Take the telecom base station as an example. As an important means of information transmission, the telecom base provides an important way of external contact for rural areas in case of disaster or emergency. Therefore, it is necessary for the telecom base station to have 24 ~ 72 hours of standby power. The capacity of fuel cells installed in Telecom base stations is about 5 kW. It is estimated that about 20% of base stations have the demand for hydrogen fuel cells, so the potential market is not small. According to the number of licenses of 4G base stations counted by NCC, there are about 100,000 base stations in Taiwan, that is, about 20,000 base stations have the demand for hydrogen fuel cells, which is the total demand capacity of 100 MW stationary fuel cell devices.

From the perspective of hydrogen fuel cell capacity of hydrogen vehicles, which depends on different kinds and various applications, but the fuel cell capacity of small vehicles is about 113 kW. According to the number of new licenses issued for 382,918 passenger cars and 47,576 trucks in 2021, if the new hydrogen fuel cell vehicles are increased by 0.1% every year, then about 430 hydrogen fuel cell vehicles will be added every year. Therefore, it is known that the hydrogen demand will increase by at least 48.6 MW every year.

It can be seen that if hydrogen energy vehicles are to be promoted in the future, the demand for hydrogen will increase significantly. Small hydrogen fuel cell vehicles are relatively less attractive to the public than pure electric vehicles, due to factors such as high cost and insufficient hydrogen refueling stations. For those large transport vehicles that cannot be fully electrified, such as ships, trains and large trucks, hydrogen fuel cells will be the primary choice. Because ships, trains, large trucks and other transport vehicles need to consume a lot of energy, and there are fixed berthing places.

The main advantage of using hydrogen energy as a power source is that it can be replenished quickly and does not need to take a long time to charge like a pure electric vehicle. Therefore, the hydrogen filling equipment for large vehicles must be more large-scale, and the large hydrogen station must produce at least 200 kg of hydrogen per day, so as to meet the needs of large vehicles. At present, the reason why it is difficult to popularize hydrogen energy in the world is mainly because price, production and infrastructure of hydrogen energy are still in the development stage. Before the popularization of hydrogen vehicles, the supply and production of hydrogen will be the primary consideration.

From the perspective of the demand for hydrogen power generation, this kind of demand should not be underestimated. Based on the valuation of the hydrogen market in Japan, the government plans to increase the hydrogen/ammonia power generation to 114.8 billion kWh in 2050, about 10% of the total power generation. Based on the calorific value of hydrogen (LHV) is 3 kWh / Nm^3, Japan will have 3,479,968 tons of hydrogen demand in 2050. Figure 8 shows the energy ratio of hydrogen/ammonia power generation in Japan in 2050.

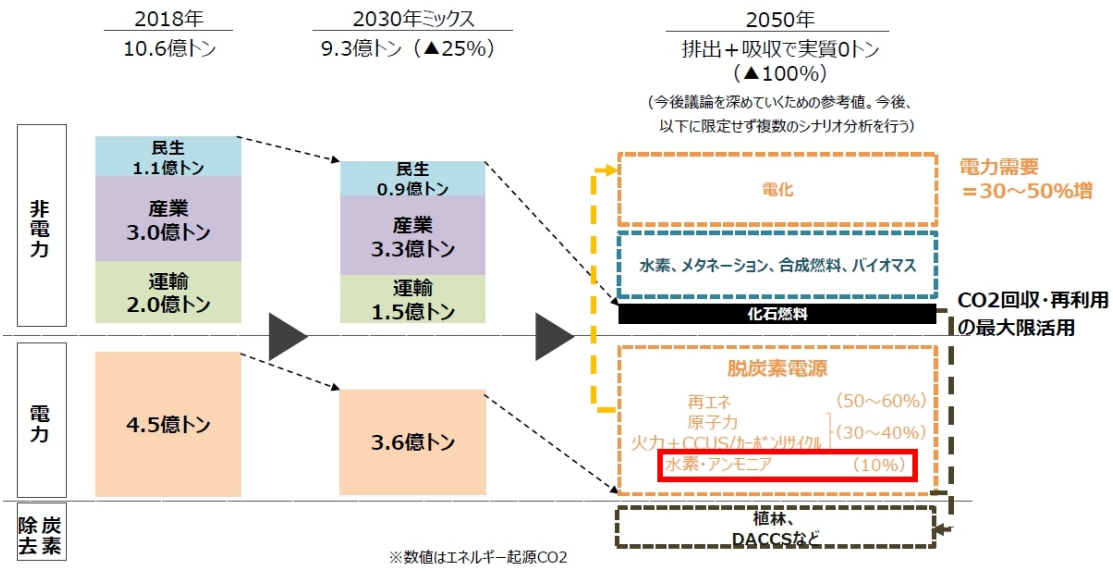

Figure 8. Energy ratio of hydrogen / ammonia power generation in Japan in 2050

Source: NEDO, Japan

In terms of hydrogen energy planning, South Korea plans different proportions of hydrogen power generation in 2050 for three different scenarios (as shown in Table 4). In response to the goal of net zero carbon emission in 2050, and taking Korean model scenario 3 as a reference, hydrogen/ammonia thermal power plants account for 21.4% and the annual power generation is 270 TWh. Based on the calculation of hydrogen calorific value (LHV) is 3 kWh/Nm^3, it can be seen that South Korea's estimated hydrogen demand in 2050 is about 8,030,695 tons.

Table 4 South Korea's "Draft of 2050 Carbon Neutralization Scenario"

Unit：TWh

Scenario	Nuclear Energy	Coal	LNG	Renewable Energy	Fuel Cell	Northeast Asia Super Grid Project (Solar and Wind)	H_2/NH_3	Byproduct H_2	Total	Carbon Emission
1*1	89.9	19.1	101.1	710.1	121.4	33.1	177.2	3.9	1,256.4	46.2
	(7.2%)	(1.5%)	(8.0%)	(56.6%)	(9.7%)	(2.6%)	(14.1%)	(0.3%)	(100%)	
2*2	86.9	0.0	92.2	710.6	121.4	33.1	159.6	3.9	1,207.7	31.2
	(7.2%)	(0.0%)	(7.6%)	(58.8%)	(10.1%)	(2.7%)	(13.2%)	(0.3%)	(100%)	
3*3	76.9	0.0	0.0	891.5	17.1	0.0	270.0	3.9	1,259.4	0
	(6.1%)	(0.0%)	(0.0%)	(70.8%)	(1.4%)	(0.0%)	(21.4%)	(0.3%)	(100%)	

*1: Maintain 7 coal-fired power plants that have not reached the service life + CCS
*2: Stop coal-fired power generation and maintain LNG power generation
*3: Completely stop coal-fired and LNG power generation

Sources: Korea 2050 Carbon Neutralization Committee

In the case of Taiwan, referring to the model of Japan and South Korea, hydrogen power generation will reach 10% of the total power generation in 2050. According to the estimation of the national total power generation of 279.8 billion kWh in 2020, if the increase rate is 30% in 2050, the total power generation will be 363.7 billion kWh. Taking 10% as the estimation of hydrogen power generation (36.37 billion kWh), about 1.08 million tons of hydrogen will be used for power generation in 2050. Referring to the situation of using hydrogen in Japan, the proportion of hydrogen used for power generation accounts for about 80% of the total hydrogen demand in Taiwan. Therefore, it can be estimated that the national hydrogen demand in Taiwan will be 1.35 million tons in 2050.

Chapter III

Analysis of Hydrogen Energy Development Potential in Taiwan

Hydrogen energy and fuel cell are clean energy that has been widely used in different power generation devices in the world. Their applications include large stationary electric generators to provide regional power or standby power. It can also be used as a power source for light vehicles and portable electronic 3C products. At present, Taiwan's hydrogen energy and fuel cell industry has complete upstream, middle stream and downstream technologies, which can not only meet the needs of commercialization, but also have the technical capacity in line with international standards.

At present stage, the cost of commercial development in Taiwan is slightly high. It is necessary to reduce production costs, establish development niche, strive for user subsidies and achieve mass production, which can greatly increase the market share. The following analyzes the development potential of hydrogen energy from the supply chain and development difficulties of hydrogen energy industry in Taiwan.

1. Hydrogen Industry Supply Chain

Taiwan's hydrogen energy and fuel cell industry is well developed. From raw materials, components, systems to peripheral products, corresponding manufacturers can provide relevant products.

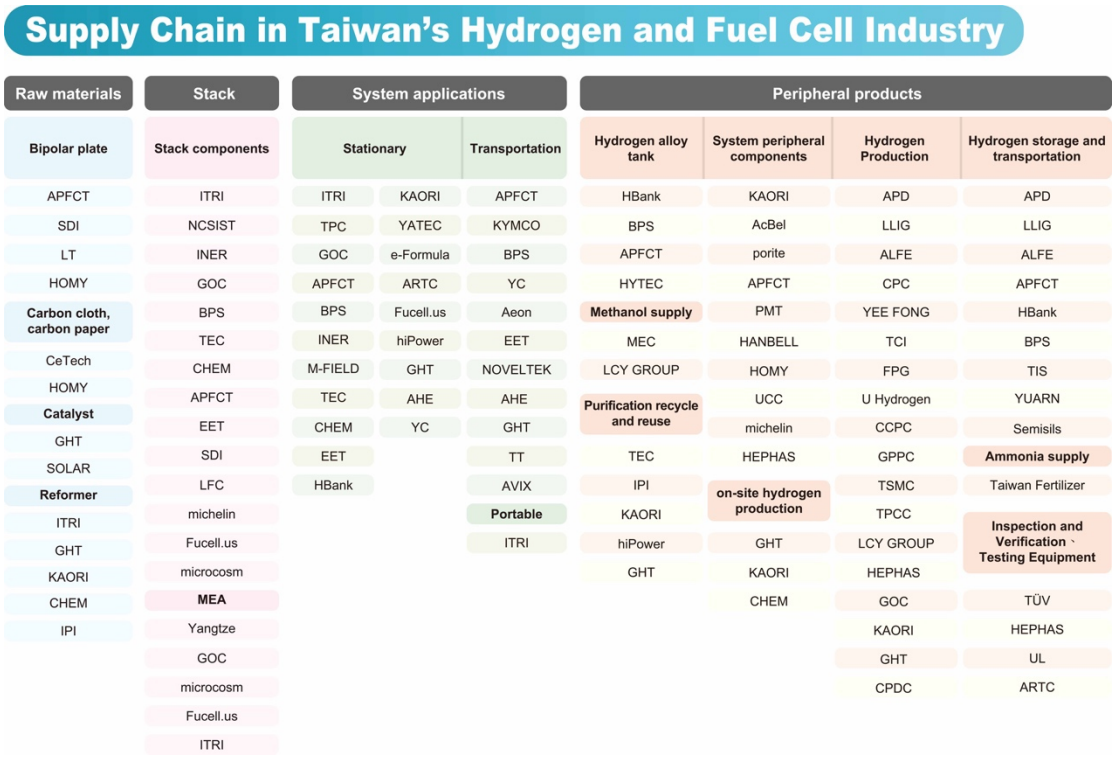

Figure 9. Supply chain of hydrogen energy and fuel cell industry in Taiwan

Source: Taiwan hydrogen and fuel cell partnership

Taiwan's main competitive advantage is that it has excellent processing and manufacturing technology, can provide key components and devices for large international companies, and has mature experience in fuel cell assembly. Taiwanese manufacturers have developed a number of hydrogen energy industrial applications, including smart grid, industrial residual hydrogen reuse, electric vehicles and the establishment of domestic and foreign partial rural hydrogen fuel cell disaster resistant communication platforms for power backup. The representatives of Taiwan's industrial supply chain are as follows:

A. Raw Material

a. Solar Applied Materials Technology Corporation

Solar Applied Materials Technology Corporation was established in 1978 and is currently an OTC company in Taiwan. It has more than 40 years of precious metal related operation and refining capacity, synchronized with the world's business model and technology. This company can provide customers with seven elements such as gold, silver, platinum, palladium, ruthenium, indium and gallium, and precious and rare metal recovery/refining services from multiple waste sources, as well as related precious metal trading, transfer, leasing and other services. This company also develops sputtering targets, evaporation materials, wires, powders, chemicals, catalysts and equipment components, which are applied to ten industries such as storage media, semiconductor, optoelectronics and energy.

B. Fuel Cell Components

a. Industrial Technology Research Institute (ITRI)

The fuel cell team of Green Energy Research Laboratory of ITRI conducts research, design and development of proton exchange membrane fuel cells. Considering the popularity of natural gas use in Taiwan, as well as regulations and standards, this team has developed a stationary cogeneration type natural gas fueled fuel cell system with the electric capacity more than 5 kW. In addition, 1 kW portable fuel cell generator has also been completed. The generator is fully automatic and can be started with one button. Through the fuel cell system of ITRI as a platform, Green Energy Research Laboratory is developing licensing technologies required for large-scale market adoption. These core technologies include system integration, hydrothermal management, fuel cell stack design, key

components of fuel cell stack, reformer and power conditioner.

The fuel cell team of Material and Chemical Industry Laboratory of ITRI has long been committed to the technical development of membrane electrode assemble, fuel cell stack and power generation system integration of both PEMFC and DMFC, so as to provide long-term power solutions. This team has completed DMFC system products and actually introduced them into the power supply application of field monitoring system. The lightweight and high-power PEMFC system introduces UAV to provide long endurance flight power, so that its flight time can reach 2 ~ 3 times that of lithium battery with the same weight. The high-efficiency hybrid power control integration technology developed by this team can regulate the hybrid output of fuel cell and lithium battery, so as to achieve the purpose of long-term and stable flight of UAV.

b. Research and Development Center of Nano-Optical and Electromagnetic Materials Technology of National Taipei University of Technology

This center is a technology R&D center supported by the Ministry of Education for technical colleges, providing industrial technology R&D and promoting two-way exchanges between industry and university. This center provides various testing services, including electrical quality testing, magnetic quality testing, optical quality testing, thermal quality testing, material structure analysis and powder characteristics testing.

The core technology of this center is the development of medium temperature anode supported SOFC, focusing on the process and optimization of fuel cell stack. By evaluating the durability and failure mechanism of fuel cell, the material, design and process of SOFC stack are improved. The main development achievements are new electrolyte and

cathode materials, production of large-area SOFC stack, and development of medium temperature SOFC stack.

c. Yangtze Company

The main technology is the technology transfer of fuel cell membrane electrode assembly (MEA) and the output of the whole plant, including roll to roll CCM production machine and automatic 7-layer MEA bonding assembly line. This company can provide 10,000 m^2/year MEA production line, 30,000 m^2/year MEA production line, 50,000 m^2/year MEA production line, and 100 ~ 2000 customized MEA samples.

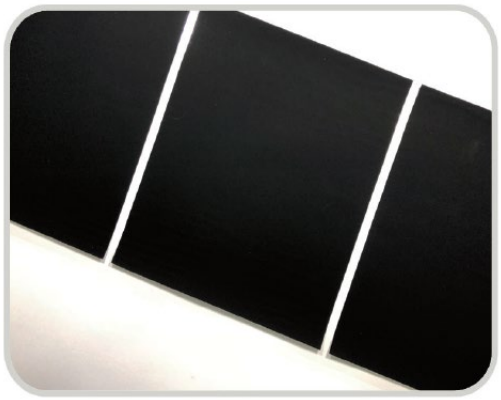

Figure 10. Yangtze membrane electrode assembly, MEA

Source: Taiwan hydrogen and fuel cell partnership

d. Fucell Company

This company has been committed to the research and development of various fuel cells for many years, with factory and warehouse. The factory has all kinds of processing machines. The professional projects include not only the production and assembly of fuel cells and battery stacks, but also the professional field of fuel cells.

Figure 11. Fuel cell stack (FCE-1.2kW-07) of Fucell Company

Source: Taiwan hydrogen and fuel cell partnership

C. System Applications

a. Chung Hsin Electric and Machinery Company (CHEM)

The main products are insulated switchgear, electric generators, electric power substation engineering, air conditioning system, power automation system, parking lot management, etc. At present, it is also the only qualified manufacturer of high-voltage gas insulated switches evaluated by Taipower in Taiwan. In recent years, this company has also actively focused on green energy issues. After the establishment of the new energy R & D center in 2008, it is committed to the development of hydrogen energy technology and fuel cells.

Combined with the strength of industry, university and research institute, this company has successfully applied for a number of technical patents and national demonstration and verification program (NDP), and has become the first manufacturer in Taiwan to officially enter the operation of fuel cells. At present, CHEM has developed well in backup power system, home/commercial cogeneration system and auxiliary power system, and will continue to develop towards clean energy in the future.

Figure 12. Methanol solution fueled reformed gas type fuel cell system (ME^2) of CHEM

Source: Taiwan hydrogen and fuel cell partnership

b. HiPower GreenTech Company

The company has a team of research and application of hydrogen energy. Through hydrogen energy technology, this company is committed to improving the environment, improving people's quality of life, reducing combustion and heat emission, and using clean energy to solve the problem of global warming. The goal is towards "energy independence" and focuses on the development of hydrogen energy technology, such as methanol fueled hydrogen generator (mGEN™), hydrogen rich tail gas recovery and purification system (HRP), and small microgrid power supply (MGrid) using methanol fueled hydrogen generator to integrate solar energy, as well as mobile independent off grid charging service (GO electric green energy charging station).

Figure 13. Alcohol fueled hydrogen power generator (mGen™) of HiPower GreenTech Company

Source: Taiwan hydrogen and fuel cell partnership

c. M-Field Energy System Company

This company has been invested in the field of fuel cell technology for more than ten years, mainly focusing on stationary fuel cell systems. Due to the depletion of fossil fuels and climate change caused by greenhouse gas emissions, this company is committed to providing cutting-edge fuel cell solutions to replace the polluting carbon economy in the hydrogen energy era.

Figure 14. Fuel cell backup power system of M-Field Energy System Company

Source: Taiwan hydrogen and fuel cell partnership

d. Toplus Energy Corporation

This company was established in 2008. Its core members are from the fuel cell team of the Green Energy Research Institute of ITRI. It designs and manufactures fuel cell stacks by itself. The stationary hydrogen fuel cell system produced by this company can provide 5-40 kW power, and has been successfully applied to the standby power supply of many industries, such as telecommunications equipment, track signals and fire department inspection equipment. These fuel cell systems are equipped with monitoring system, which can remotely monitor the operation, power supply and hydrogen consumption.

Figure 15. Fuel cell power system of Toplus Energy Corporation

Source: Taiwan hydrogen and fuel cell partnership

e. YC Synergy Company

This company focuses on the R&D, production and sales of fuel cell core technology, and its service scope includes power plant, fuel cell commercial vehicle, ship and other powertrain systems (15 kW to several MW large power generation systems). This company's products can be used in a variety of application fields, and provide consistent operation

from design, proofing, mass production to after-sales service, so as to help customers complete prototype development, matching and adjustment, as well as mass production and introduction to market as soon as possible.

Figure 16. Hydrogen fuel cell module of YC Synergy Company

Source: Taiwan hydrogen and fuel cell partnership

f. Asia Hydrogen Energy Corporation

This company is committed to developing green energy systems, promoting the application and commercialization of fuel cells, and developing reliable and efficient fuel cell systems, safe hydrogen storage and filling systems, and complete hydrogen energy environmental solutions. This company has more than 20 years of experience in fuel cell development, working closely with world-renowned enterprises and uses reliable, stable and efficient components.

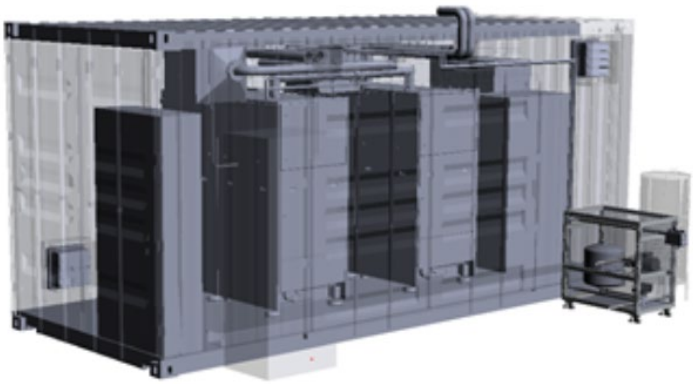

Figure 17. Hydrogen CHP system (20kW) of Asia Hydrogen Energy Corporation

Source: Taiwan hydrogen and fuel cell partnership

D. Peripheral Products

a. AcBel Polytech Incorporation

Founded in 1981, with continuous technological innovation and customer development, this company has entered the list of leading manufacturers in the global power supply industry with power management technology as the core. At present, this company is actively engaged in the research and application of green energy, such as the development of electric vehicle power supply, smart grid, solar power field construction, clean new energy power generation system, energy storage equipment, medical and smart home equipment power supply and other related products, as well as produce high-efficiency energy-saving and carbon reduction products.

b. Hanbell Precise Machinery Company

This company founded in 1994, is the first company in relevant industries in Taiwan to pass ISO 9001 certification. It is a national "important scientific and technological enterprise" approved by the Bureau of Industry, MOEA. The capital is NT $850 million. At present, there are three production bases, namely Shanghai factory in China, Guanyin factory and Taichung factory in Taiwan. It is one of the few large manufacturers focusing on the design and manufacture of compressors and vacuum pumps in the world. The market share of both Taiwan and China are the first, and the global market is among the top five.

Figure 18. Dry screw vacuum pump of Hanbell Precise Machinery Company

Source: Taiwan hydrogen and fuel cell partnership

c. Uni-Calsonic Corporation

The main products of this company are aluminum radiator, oil cooler and motor fan of automobile and locomotive. The products of heat dissipation system are complete, including cars, recreational vehicles, freight trucks, locomotives, ATV and agricultural machinery. For decades, it has been committed to developing high-performance and high-quality heat dissipation system products, and cooperating with domestic and foreign automobile, locomotive and agricultural machinery customers to independently develop and design. Radiator products are exported to Japan, Europe, Russia, South America and China.

d. Air Liquide Far Eastern Company

In 1987, it was jointly established by French Liquide Air Group and Taiwan Far East New Century Group, which have been operating for more than 100 years. This company has more than 40 gas production plants, with services covering all-round solutions such as nitrogen, oxygen, argon, hydrogen, industrial and electronic special gases, and electronic advanced

material gases. This company is the first large gas company to commit to carbon neutrality by 2050. It can provide customers with a wide range of low-carbon solutions, and plan to invest about EUR 8 billion in the low-carbon supply chain to accelerate the development of low-carbon energy ecosystem.

Figure 19. 25 MW low carbon water electrolysis plant of Air Liquide Far Eastern Company

Source: Taiwan hydrogen and fuel cell partnership

e. Linde Lienhwa Industrial Gases Company

This company is invested and established by Germany Linde Group and Taiwan Lianhwa Industry Co., and is the largest industrial gas manufacturer in Taiwan. Through close cooperation with Linde Group companies all over the world, this company can provide different kinds of high-quality gases and gas application technologies.

f. Kaori Heat Treatment Company

Through the pursuit of innovative heat treatment technology and

continuous development, research and introduction of new technology, this company has successfully developed key components and system equipment for many industries such as plate heat exchanger and roller. In order to move towards the direction of net zero emission and clean energy in the future, this company provides customized solutions for heat exchange, hydrogen production, purification and thermal production, as well as develops new technologies for the treatment of waste organic solvents and the recycling of residual hydrogen.

Figure 20. Methanol fueled hydrogen generator of Kaori Heat Treatment Company

Source: Taiwan hydrogen and fuel cell partnership

g. Green Hydrotec, Inc.

This company is the world's leading supplier of on-site methanol fueled hydrogen generator, specializing in the design technology and miniaturization of the unit. Using unique catalytic heater and reactor design, this company has developed a compact, efficient and durable methanol fueled hydrogen generator. The reaction temperature is 270 ~ 280 ℃, and it takes only 60 minutes from the cold state to the start of hydrogen production. These hydrogen generators run stably for a long time and has

accumulated more than 39,480 hr. It has been widely used in Taiwan, China and Japan to help users reduce hydrogen storage and transportation costs by 40 ~ 60% and decrease energy consumption. These units can avoid storing high pressure hydrogen on site and improve site safety.

Figure 21. Methanol fueled hydrogen generator with 6N+ purity and CO ≤ 0.1 ppm of Green Hydrotec, Inc.

Source: Taiwan hydrogen and fuel cell partnership

h. General Optics Corporation

This company is a global supplier of key components for hydrogen utilization and production. Its main products are high-quality hydrogen generators and MEA modules for fuel cells. Customers are located in Taiwan, Japan, Singapore, Germany and other places, including front-line enterprises in various industries such as semiconductor, chemical, plastic and petrochemical factories.

Figure 22. Hydrogen generator of General Optics Corporation

Source: Taiwan hydrogen and fuel cell partnership

i. Hephas Energy Company

This company has invested more than 20 years in the research and development of fuel cell testing equipment, new energy cells, P2G energy storage cells, fuel cell power generation systems and other related testing and research fields, and has become a leading supplier in the world in the field of fuel cell testing. For all parameter management related to fuel cell testing, such as temperature, humidity, pressure, flow, load, etc., this company can provide complete and comprehensive product solutions, covering products from single cell to large stack.

Figure 23. Testing Equipemnt of Hephas Energy Company

Source: Taiwan hydrogen and fuel cell partnership

2. Hydrogen Energy Development Difficulties

With the improvement of carbon reduction awareness, 137 countries around the world have announced the development towards net zero emissions as of August 2021. In order to achieve the sustainable development situation of net zero emissions, they will gradually move from carbon economy to hydrogen economy. The leading regions in the development of global hydrogen energy economy are mainly concentrated in East Asia, the United States and Europe. The following analyzes the difficulties of Taiwan's hydrogen energy development in aspects of policy, technology and market.

a. Aspect of Policy

Comparing with Europe, the United States, Japan and South Korea, Taiwan has less promotion resources and funds for hydrogen energy and fuel cell industries, and also lacks clear promotion policies for niche products. Therefore, manufacturers need to seek international cooperation by themselves. However, Taiwan's hydrogen fuel cell industry has clear promotion policies such as solar energy and wind energy. Fuel cells take hydrogen as the energy carrier and do not belong to renewable energy, which makes it difficult for fuel cells to become the first choice for users to set up or plan renewable energy systems.

b. Aspect of Technology

At present, domestic manufacturers mainly research and develop 5 kW fuel cell system, and the power generation capacity can only supply small power requirement. If one wants to use 20 kW fuel cells as backup power

in rural areas, then needs to set up four sets of fuel cell systems, but the rural areas can only be set up with small area and difficult handling.

c. Aspect of Market

There is a lack of hydrogen fuel cell standard integration organization in Taiwan, and it also fails to timely respond to industrial R&D achievements and policy support needs. Due to the lack of natural resources in Taiwan, the cost of hydrogen production is higher than that in foreign countries. In large-scale application, it is necessary to seek other economically effective hydrogen sources. Taiwan's own domestic demand market is small, and its products cannot be mass produced to achieve economies of scale to reduce costs.

Taiwan's electricity price is too low, making it difficult for manufacturers to make profits. Hydrogen energy infrastructure is insufficient, and the difficulty of fuel transportation also needs to be considered. International standards related to hydrogen fuel cell technology have been announced one after another, but the progress of domestic testing, verification and standard formulation is behind schedule, which affects the industrial development and international integration.

At present stage, the commercial development cost of hydrogen energy and fuel cell in Taiwan is high, and compared with the common types of renewable energy (such as solar energy and wind energy), people and enterprises have low awareness and acceptance of fuel cell, or keep incorrect information, which is unfavorable to the promotion operation.

Chapter IV

Prospects for Taiwan−UK Cooperation

With the improvement of global awareness of carbon reduction, 195 members of the United Nations signed the Paris Climate Agreement on December 12, 2015 to jointly curb the trend of global warming. In addition, 137 countries around the world have announced the development towards net zero emissions as of August 2021, and they will gradually move from carbon economy to hydrogen economy.

The development of hydrogen energy and fuel cells in Taiwan and UK has many unique conditions and characteristics in global fuel cell R&D countries. The following are the prospects of future exchanges and opportunities in the field of hydrogen energy between Taiwan and UK from the aspects of policy and industry.。

1. Policy Learning

The UK plans to achieve 5 GW of low hydrocarbon hydrogen production capacity by 2030 for the entire economy. Britain’s Hydrogen Blending Delivery Plan has been published. It is expected that by the end of 2023, five natural gas network companies will mix 20% hydrogen into natural gas delivered to 85% (about 23 million) households and millions of enterprises across the country, which means that gas-fired power plants will be able to use mixed hydrogen to generate cleaner electricity. The British government also released the hydrogen BECCS innovation plan in January 2022 to support the production of hydrogen from biomass raw materials and related technologies combined with carbon capture.

Taiwan announced amendments to Renewable Energy Development

Regulations in 2019, aiming to increase the capacity of renewable energy power generation units by 20%, which will reach to 27 GW by 2025. Large power users with a specified power contract of more than a certain capacity (5000 kW) should set up 10% green power, which will encourage enterprises to set up renewable energy equipment by themselves, and promote the development of hydrogen energy and fuel cell industry. Taiwan and Britain can hold seminars to exchange and share practices and strategies according to each other's policy goals and visions.

2. Industrial Cooperation

In terms of hydrogen production, Taiwan is now moving towards the goal of green power policy in 2025. Britain has abundant renewable energy such as wind power generation, as well as large-scale electrolytic equipment and green hydrogen production technology. Taiwan and Britain can exchange hydrogen production, transportation and storage technologies, and plan to cooperate to set up a demonstration field of green hydrogen production in Taiwan.

In terms of enterprise cooperation projects, Taiwan has a complete hydrogen energy and fuel cell industry chain, which can provide fuel cell components to the UK. Taiwanese manufacturers can conduct technical cooperation or even joint research and development with leading British manufacturers, such as Ceres and Petrofac, so as to realize regional large-scale renewable energy electrolytic hydrogen production, which can be used as energy storage, stable power grid, fuel cell generator, and hydrogen energy vehicle. In addition, Taiwan and the UK each enjoy import and export advantages in China and Europe. The two sides can invest in each other to set up factories, so as to jointly explore overseas markets and

promote hydrogen energy and fuel cell technologies and related products.

3. Think Tank Exchange

The development of fuel cells in the public sector in Taiwan is mainly dominated by the Bureau of Energy of MOEA, and the relevant think tanks and research institutions include ITRI and TIER and others. TIER serves as the Secretariat of Taiwan Hydrogen and Fuel Cell Partnership (THFCP) as an integrated platform for promotion and exchange among industry, government, academia and research circles. There are more than 50 members in THFCP, covering all of the upstream, middle stream and downstream of industrial chain in Taiwan.

The UK's hydrogen and fuel cell research promotion system is the Department for Business, Energy and Industrial Strategy, which announced a new capital policy in 2022, and planned to invest £ 240 million in the Net Zero Hydrogen Fund (NZHF) to accelerate the commercialization of low-carbon technologies and net zero systems. Besides, the relevant research promotion unit is the UK Innovation Agency.

In terms of integrating the voice of the industry, promoting technological development and education promotion services, there is the Scottish Hydrogen and Fuel Cell Association (SHFCA). THFCP and SHFCA have signed a letter of intent on cooperation, which can provide a platform for future hydrogen energy development cooperation and urge Taiwan and Britain to jointly study and formulate the direction of cooperation.

Chapter V

Conclusions and Recommendations

2021 is the starting point for large power users in Taiwan to be given the responsibility of using green power. According to the amendment to the renewable energy development regulations announced by MOEA in 2019, it is clearly stipulated that large power users with a power contract of more than a certain capacity (5000 kW) should set up 10% green power. As the largest energy group in Taiwan, Formosa Plastics Corporation has focused on three major fields: new energy (lithium iron phosphate battery, fuel cell), solar power generation and wind power generation. Many small and middle enterprises also participated in the RE100 Climate Declaration in 2020 and jointly promised to use at least 10% green electricity in 2025.

When the use of green power by enterprises has become a global trend, the stable supply of renewable energy and the perfection of the power industry system are also very important. Taiwan published the amendment of Electricity Act in 2017, and free trading and voucher market of green electricity was officially opened, and the ways for enterprises to obtain green electricity had been more diversified.

Britain has technological innovation and leading advantages in the hydrogen energy industry, and as a major country with key technologies of hydrogen energy and fuel cell, as well as has the development potential of mass production of green hydrogen. Taiwan has complete upstream, middle stream and downstream technologies in the hydrogen energy and fuel cell industry chain, which can meet the needs of practical commercial applications such as OEM and integration, and also has technical capacity in line with international standards.

Under the 2050 net zero carbon emission target, Taiwan estimates that

the future hydrogen gas supply will be in short supply. At the same time, the UK can seek an Asian field as a demonstration of hydrogen energy application. In the future, Taiwan and the UK can integrate policy exchange, technology and industrial cooperation, as well as the various advantageous technological innovation and production capacity, such as large-scale electrolysis technology, green hydrogen production, hydrogen fuel cell vehicle, hydrogen station construction and maintenance, green hydrogen demonstration field, and research and development of key components. These items can be using as the main focus of mutual cooperation, and both sides can work together to help the world enter the era of hydrogen economy.

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Appendix：List of Taiwanese Hydrogen Energy and Fuel Cell Manufacturers

No.	Company	Type of Fuel Cell
1	AcBel Polytech Inc.	Switching Power Supply, Smart Grid, EV Power Solutions,Energy Storage System, BMS, EMS, Clean & Renewable Energy Power, Cell Data Center Solution.
2	Air Liquide Far Eastern Ltd.	Supplies high quality gases and total solution for the needs of electronics & large industries markets, industrial merchant customers and healthcare patients.
3	Air Products and Chemicals, Inc.	Hydrogen charging station, hydrogen charging equipment, liquid and gas oxygen, nitrogen, Argon, helium, carbon dioxide, standard gas, environmental protection gas, electronic gas, welding gas, mixed gas and related equipment and services
4	Asia Hydrogen Energy Corporation	PEMFC systems, SOFC systems, Biogas power solutions,Key components of fuel cell system, Engineering design for projects.
5	Asia Pacific Fuel Cell Technologies	1.Stacks (1.8kW) 2.Fuel Cell System for light electrical vehicle (scooter, pallet truck, golf cart) 3.Low pressure Hydrogen Storage (Metal hydride)
6	Automotive Research and Testing Center	R&D, testing and certification on vehicles
7	Boyam Power Systems Co., Ltd.	PEMFC Stack, Power system, AB5 Metal hydride canister
8	Center of EMO Materials and Nanotechnology National Taipei University of Technology	Intermediate Temperature Anode Supported SOFC
9	CETECH CO., LTD.	carbon paper, carbon cloth, Titanium Fiber Paper, Graphite felt, PAN, Natural Graphite Sheet, Intelligent Graphite Sheet
10	China Steel Corporation	Plates, bars, wire rods, hot and cold rolled coils, electrogalvanized coils, electrical steel coils, hot-dip galvanized coils, and Ti/Ni-base alloy
11	Chung Hsin Electric & Machinery Mfg. Corp. Ltd. (CHEM)	ME² Power Fuel Cell System,Hydrogen Dispenser,Smart Hybrid Inverter,Micro Grid solution
12	Digisine Energytech Co., Ltd.	1,500 W~15,000 W Small Green Energy Smart Grid/ 1,500 W Off-Grid Smart Power System/IoT Wind Generator/IoT Solar Power Point Tracking Charge Controller/1,500 W Hybrid Power Converter/Por Power

		Supply
13	DUPONT TAIWAN LIMITED	MEA, Nafion® Membrane & Solution
14	Eco-Energy Technology Co., Ltd. (EET)	PEM FC stacks and power system for generators, vehicles,etc.
15	e-Formula Technologies, Inc.	Energy Production, Micro-Grid System, Energy Management,AIOT solution provision, Data Center & Big Data Enabler.
16	FUCELL Co., Ltd.	Fuel cell, Vanadium cell, Hydrolysis cell, Hydrogen machine, Hydrogen water machine, Graphite plate
17	GALLANT PRECISION MACHINING CO., LTD.	Intelligent Factory and Consultant ,Flat Panel Display Processing Equipment ,Semiconductor Processing & Detecting Equipment ,Contact Lens Production Equipment & Construct,Intelligent Automation System and ROBOT,In Vitro Diagnostic Products,AOI Equipment, Wet Process / Chemical Technology Equipment,Solar Cell Production Equipment & Construct,Laser Application Equipment ,Precision Machinery / Mold Manufacture
18	GOC International Technology CORP.	MEA, Hydrogen Generator, Integrated Regenerative Fuel Cell System.
19	Green Hydrotec, INC.	On-site hydrogen generator
20	Green Technology Research Institute,CPC Corporation, Taiwan	Reformer (Feedstock: Nature Gas) on 5 kW SOFC
21	Hanbell Precise Machinery Co., Ltd.	Screw Compressor, Screw Air Compressor, Dry Vacuum Pump, Centrifugal Compressor
22	HBank Technology Inc.	Hydrogen Storage in Metal Hydride
23	Hephas Energy Co., Ltd.	Fuel Cell Test Equipment
24	hiPower Green Technology Co. Ltd.	·mGen™ - Methanol fuel cell power generator ·mGrid - Micro-grid system ·Hydrogen-rich gas recycle and purify system ·MeOH Fuel mixer ·MyGo green charging station
25	Industrial Technology Research Institute /Institute of Green Energy and Environment (ITRI/GEL)	Proton Exchange Membrane Fuel Cell (PEMFC)
26	Industrial Technology Research Institute /Material and Chemical Laboratories(ITRI / MCL)	PEMFC Membrane Electrode Assemblies、PEMFC Stack、PEMFC power system、PEMFC Powered UAV System
27	Institute of Nuclear Energy Research (INER)	cell, stack, power system, reforming catalyst
28	Integrated Plasma Inc.	ARH-5000 Ammonia Reformer
29	Kaori Heat Treatment Co., Ltd.	Hydrogen Generator, Fuel Cell System, Natural Gas Fuel Cell System, Methanol Fuel Cell System Hydrogen

		production system
30	KUOZUI MOTORS, Co., Ltd.	Manufacture and export of passenger cars, commercial trucks,and various car parts (Corolla Altis, Corolla Altis Hybrid, Corolla Cross, Corolla Cross Hybrid, Sienta, Vios, Yaris, HINO trucks,Bus, etc.)
31	Leadtech International Co., Ltd.	Precision Progressive Die. Stamping Part.
32	Leatec Fine Ceramics Co., Ltd	SOFC single cell, SOFC stack
33	Linde Lienhwa Industrial Gases Co. Ltd.	Oxygen, Nitrogen, Argon, Acetylene, Hydrogen, CO2, N2O, NH3,Electronics Special Gases, Liquid Helium, H2, Fueling Solution.
34	M-FIELD Energy Ltd.	Fuel Cell
35	Michelin Tire Taiwan Co., Ltd.	Tires
36	National Cheng Kung University Advanced Green Industrial Technology Research and Certification Center	Graphite and metal bipolar plate PEMFC system, Hydrogen UAV.
37	New Energy Association Of Taiwan	Promote the development of Taiwan's new energy industry, create an environment for the new energy industry, promote the use of new energy, and achieve a long-term and straightforward country as a non-nuclear homeland.
38	PLUS METAL TECH CO., LTD.	Solid Oxide Fuel Cell (SOFC)
39	SDI Corporation	LEAD FRAMES, Electronic parts, OFFICE PRODUCTS, Fuel cell stack
40	Semisils Applied Materials Corp., Ltd.	Silicon Dioxide, Silicon Carbide, Sodium Silicate, Hydrogen
41	Sojitz Corporation	Sojitz Group is engaged in a wide range of businesses globally, including manufacturing, selling, importing, and exporting a variety of products, in addition to providing services and investing in diversified businesses, both in Japan and overseas. Sojitz operates with a 7-division structure comprising the Automotive Division; the Aerospace & Transportation Project Division; the Infrastructure & Healthcare Division;the Metals, Mineral Resources & Recycling Division; the Chemicals Division; the Consumer Industry & Agriculture Business Division; and the Retail & Consumer Service Division.
42	Solar Applied Materials Technology Corp.	Recycling and Refining of Spent Catalyst, Pt catalyst, Pd catalyst
43	Taiwan Electric Research & Testing Center(TERTEC)	PEMFC, DMFC

44	Taiwan Institute of Economic Research (TIER)	Hydrogon & Fuel Cell Market Report
45	Taiwan Power Company (Taipower)	Its business scope includes generation, transmission, distribution, and sales of electricity.
46	Toplus Energy Corporation	PEMFC、Hydrogen Purify and Recovery System
47	TÜV Rheinland Taiwan Ltd.	Training, consulting, testing, inspection, quantification, verification and validation service for product safety, process safety, quality & reliability, carbon neutrality and carbon footprint for equipment and management system of whole hydrogen value chain.
48	UL Taiwan	Certification ,Inspection, testing, inspection, auditing, consulting and training
49	Unelectra International Corp. (UIC)	cast resin transformer, cast resin busbar、Bipolar plate for proton exchange membrane fuel cell
50	Uni-Calsonic Corporation	Radiator of vehicles
51	Union Storage Energy System LTD.	Customized battery pack, battery management system, energy storage microgrid system
52	Xing Yang Technology Logistics Co., Ltd.	Steel transportation and freight services, hydrogen fuel transportation services, mobile hydrogen refueling vehicles, fuel cell stack components, corrosion-resistant battery components, household fuel cell generators, hydrogen fuel cell stackers and hydrogen fuel cell related technology research and development equipment manufacturing and Services, electric shock rods for steelmaking furnaces, pig iron scrap and various steelmaking materials, various renewable energy power generation
53	Yangtze Energy Technologies, Inc.	Automatic PEMFC-MEA production line,Customized MEA samples production.
54	Yatec Engineering Corporation	Renewable Energy System Integration, Process System Integration, Micro Grid & SCADA System
55	YC SYNERGY Co., Ltd.	Distributed Fuel Cell Power Station, Vehicle/Maritime Fuel Cell System, Backup Power