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GERMANY'S NATIONAL HYDROGEN STRATEGY

—SERIOUS EFFORTS TO REALIZE A DECARBONIZED SOCIETY; DEVELOPMENT OF GREEN HYDROGEN SUPPLY INFRASTRUCTURE IS THE CHALLENGE —

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SUMMARY

- In June 2020, the German government announced its National Hydrogen Strategy, which includes the use and diffusion of "green hydrogen" produced exclusively from renewable energy sources as a pillar of its climate change countermeasures.
- The strategy aims to foster a next-generation export industry by promoting the introduction of hydrogen utilization facilities and supporting the development and diffusion of technologies (PtG and PtL) that convert surplus electricity derived from renewable energy sources into hydrogen, gaseous fuels, and liquid fuels.
- Based on the prediction that it will be impossible to meet all future demand for green hydrogen through domestic production, Germany has begun to work on green hydrogen production in collaboration with the Netherlands and France. North Africa, Ukraine, and Russia are also seen as potential suppliers, and Germany intends to make the most of the existing natural gas pipeline network inside and outside the EU for hydrogen distribution.

INTRODUCTION

As the public and private sectors in Europe accelerate their efforts to build a hydrogen society, attention is focused on Germany, which has been the most proactive in expanding the use of hydrogen in the region. In order to reduce greenhouse gas emissions from the transportation sector, the German government has promoted hydrogen and fuel cell technology innovation programs since 2006, and announced a full-fledged National Hydrogen Strategy in June 2020. Emphasis is placed on the utilization of renewable energy-derived "green hydrogen," and efforts will focus on the storage of renewable energy, its use in energy-intensive industries, and the expansion of its use as an industrial raw material. The targets of the German strategy are broader in scope than the Japanese government's Basic Hydrogen Strategy, which focuses mainly on the use of hydrogen as a power source.

This paper provides an overview of Germany's National Hydrogen Strategy. It will introduce the background of the government's strategy, and summarize its main contents and measures to promote the introduction of hydrogen technology into German industry. After confirming the current industry trends and practical applications, the paper will summarize the movements surrounding the construction of a green hydrogen supply network and present the points worthy of attention in the future.

1. A BRIEF HISTORY OF THE BIRTH OF THE NATIONAL HYDROGEN STRATEGY

1.1 A century and a half from the discovery of the principle of fuel cells to their commercialization

In 1839, the German-Swiss scientist Schönbein discovered the principle of electricity generation through an electrochemical reaction between hydrogen and oxygen. Later, in 1866, Werner von Siemens, the founder of the German heavy electric machinery giant Siemens, developed the dynamo that converts rotational motion from water vapor into electricity, and research on fuel cells using hydrogen and oxygen as fuel was pushed aside in favor of simpler methods of generating electricity. Regarding the potential of fuel cells, Jules Verne, the father of science fiction novels, predicted in a 1875 novel that hydrogen extracted from water would replace coal as the energy source of the future, but from then it took about a century for research into the practical use of highly explosive hydrogen for power generation to begin in earnest.

The proof of the practicality of fuel cells through their use in the US manned space flight program in the 1960s and the oil crisis of the 1970s stimulated research on the use of hydrogen as a next-generation energy source. In 1990, the California Air Resources Board enacted Low Emission Vehicle (LEV) regulations that required a certain percentage of vehicles sold to be zero-emission, prompting automakers to begin full-scale development of bi-fuel vehicles, which can switch to hydrogen fuel, and fuel cell vehicles. In 2000, when BMW unveiled its 750hL bi-fuel car with a hydrogen-fueled engine, Fritz Vahrenholt, then director of the renewable energy unit of Deutsche Shell AG, said that at least 50% of new cars sold in Germany would be powered by hydrogen by 2020. However, that prediction did not come true, especially since the supply infrastructure necessary for the mass production and procurement of hydrogen was not developed.

1.2 The Paris Agreement increased momentum of hydrogen utilization in Europe

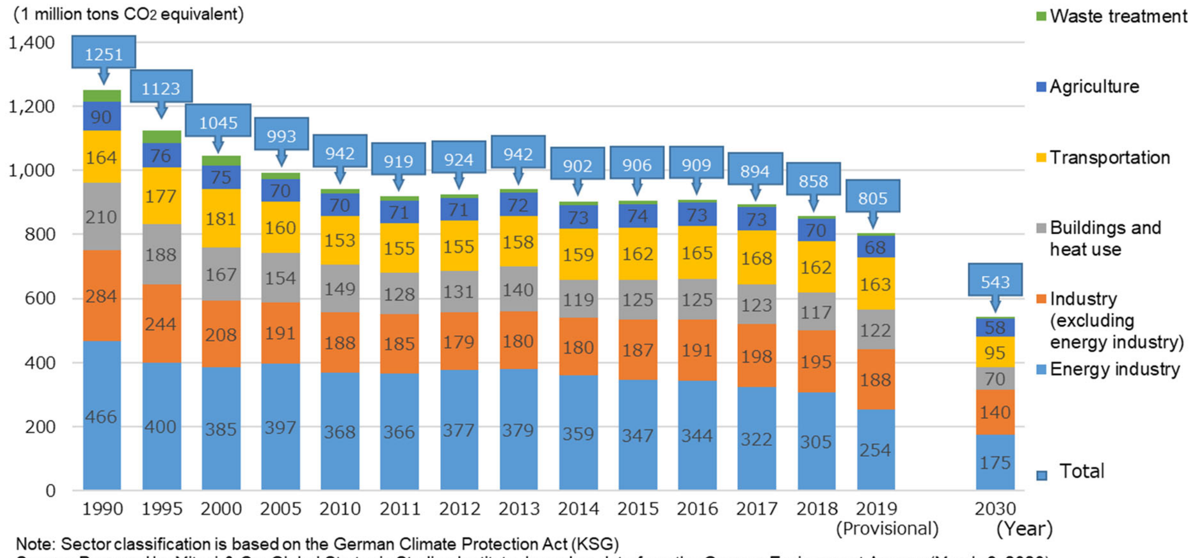
The 2015 Paris Agreement set a goal of limiting the average global temperature increase to less than 2 °C (preferably less than 1.5 °C) compared to pre-industrial levels. Against this background, momentum for the use of hydrogen, which had not previously received widespread attention in the EU, has increased. In 2018, the European Commission released the long-term vision “A Clean Planet For All”, a policy document that sets the direction for Europe's decarbonization by 2050. In this document, the use of hydrogen was specified in a total of nine scenarios, spurring the spread of hydrogen in the region. The European Green Deal, an EU growth strategy published in 2019 based on the same policy document, focuses on achieving a sustainable economy and society in the EU, emphasizing that building hydrogen networks in smart infrastructure is also essential.

Germany is one of the most active EU member states in expanding the use of hydrogen. As a measure to reduce emissions in the transportation sector, which accounts for 20% of its greenhouse gas emissions, the government already formulated the National Innovation Programme Hydrogen and Fuel Cell Technology (NIP) (NIP I: 2007-2016, NIP II: 2017-2026) in 2006. It provided 1.65 billion euros in support for R&D and commercialization of hydrogen technology by industry, government, and academia until 2019. However, unlike all the other sectors, greenhouse gas emissions in this sector did not start to decline compared to 2005 (Figure 1), and the introduction of stronger measures became necessary.

The Fukushima nuclear power plant accident caused by the Great East Japan Earthquake in 2011 prompted the German government to pledge to implement an "energy transition" (including the nuclear power phase-out by 2022) to change its conventional energy mix to focus on renewable energy. In addition, its Climate Action Plan 2050, prepared in 2016, set targets to reduce greenhouse gas emissions by 80-95% by 2050 compared to 1990 levels and to increase the share of renewable energy in final energy consumption to 60%.

This has made it an urgent issue for the government to strengthen the storage capacity of renewable energy-derived electricity, the supply of which is unstable because it is easily affected by weather and other natural conditions, and to convert it into fuel for transportation.

Figure 1 German greenhouse gas emissions



Note: Sector classification is based on the German Climate Protection Act (KSG)
Source: Prepared by Mitsui & Co. Global Strategic Studies Institute, based on data from the German Environment Agency (March 9, 2020)

2. THE NATIONAL HYDROGEN STRATEGY, FOCUSING ON PROMOTING GREEN HYDROGEN

2.1 Hydrogen strategy budget totals over 21.3 billion euros

The German government has placed hydrogen at the center of its decarbonization efforts in its National Hydrogen Strategy announced in June 2020. The strategy covers the entire value chain, from related technologies to production, storage, infrastructure, and utilization, including logistics, quality assurance, and consumer protection. The aim is to promote drastic reforms in the German economy and society. Therefore, as part of the current energy transition policy, the core goal of the National Hydrogen Strategy is to use hydrogen for renewable energy storage and as a fuel for transportation, and to make it an important raw material for industry (Figure 2).

Compared to the previous NIP program, the scope of the strategy has been broadened with the addition of the goal to expand the use of hydrogen as a raw material for industrial use. Hydrogen as an industrial raw material, for example, is essential for the synthesis of ammonia and high value-added chemicals (HVC), which are used as raw materials for chemical fertilizers and plastics. It also plays an important role as a coolant for turbine generators, a shielding gas for welding and thermal cutting, and a saturation catalyst for refined and processed edible oils and fats. Furthermore, it is attracting attention as a reducing agent to replace coke in the steel industry.

The government will invest 12.36 billion euros by 2026, plus the hydrogen promotion budget (nine billion euros) from the coronavirus economic stimulus package, which was decided just before the publication of the National Hydrogen Strategy. The 38 measures planned are categorized into the following six areas. (1) Production of hydrogen: four measures, (2) Utilization of hydrogen (transportation: nine measures, industry: four measures; buildings and heat utilization: two measures), (3) Hydrogen supply infrastructure: three measures, (4) Promotion of education and R&D: seven measures, (5) Hydrogen diffusion in the EU: four measures, (6) Global market development and coordination: five measures.

Figure 2 Overview of Germany's National Hydrogen Strategy

Major policies

Budget	Policy details
3.6 billion euros	Support for conversion to fuel cells for automobiles, trains, and coastal and inland water transportation vessels (~2023)
3.4 billion euros	Support for development of hydrogen refueling and recharging infrastructure (~2023)
1.91 billion euros	Support for hydrogen technology research (e.g., NIP II, a program for innovation in hydrogen and fuel cell technology) (~2026)
1.1 billion euros	Support for PtL facilities that convert electricity to liquid fuel (~2023)
1 billion euros	Investment in new technologies and large-scale facilities (~2023)
700 million euros	Support for the introduction of fuel cell heaters (~2024)
600 million euros	Support for hydrogen research and industrialization through the Real-World Laboratories program (~2023)
50 million euros	Support for research on the practical application of fuel cell powered airplanes and ships (~2024)
Total 12.36 billion euros	
＋	
9 billion euros	Appropriation from Coronavirus economic stimulus package ・Support for the launch of the hydrogen market (7 billion euros) ・International collaboration and cooperation (2 billion euros)

Core objectives of the strategy

(1) Green hydrogen will play a central role in the promotion and completion of Germany's energy transition policy

- For decarbonization
- As a means of storing renewable energy
- As an energy source
- As raw material

(2) Fulfilling the global responsibility to meet the challenge of reducing CO_2 emissions

(3) Building a hydrogen society is a collective task for the EU

Production and procurement forecasts

Hydrogen use in Germany

2030: 90-110 TWh
2050: ~380 TWh

Green hydrogen production

Domestic production
2030: 14 TWh
(4,000 hours full-load operation of water electrolyzer, average energy efficiency ratio 70%)

Facility capacity
2030: 5 GW
2040: 10 GW or more

Imports
2030: Almost none
2050: Imports will account for the majority of demand

Source: Prepared by MGSSI based on data from the German Federal Ministry for Economic Affairs and Energy (Die Nationale Wasserstoffstrategie) and Research Center for Energy Economics (FfE)、Munich (www.ffegmbh.de/images/stories/Dekarbonisierung/1003_Nationale_Wasserstoffstrategie/Infografik_nationale_Wasserstoffstrategie_final.png)

2.2 Shift from gray hydrogen to green hydrogen

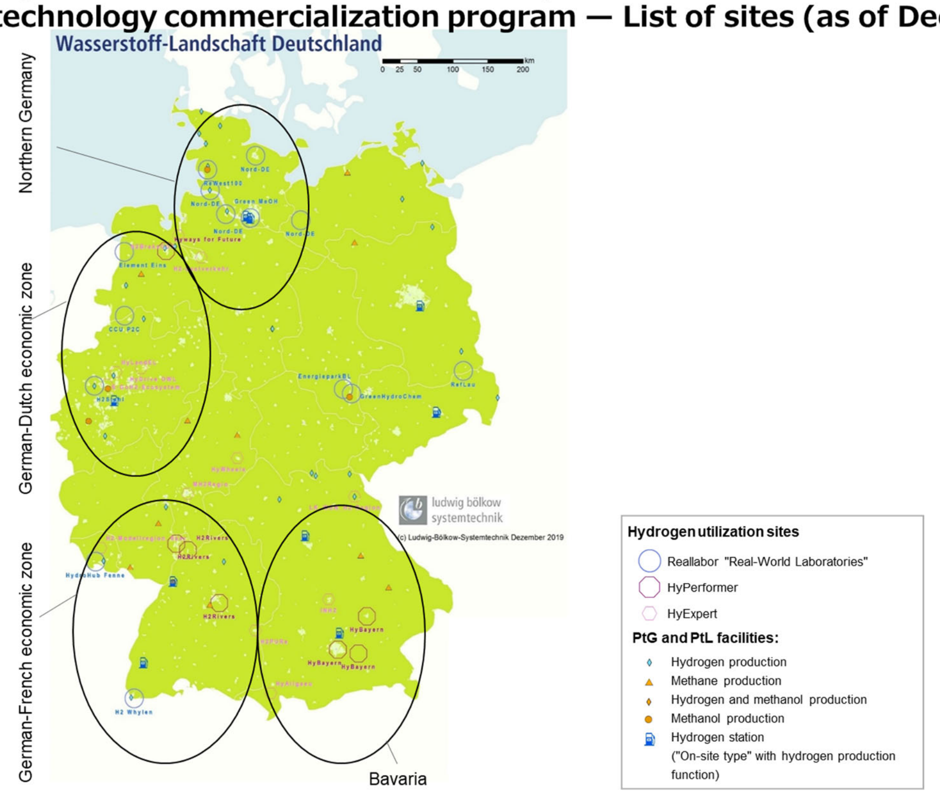
The German industry currently uses about 1.7 million tons (55 TWh) of hydrogen per year, and the government expects this to double by 2030 as the strategy sparks new demand. However, 95% of the hydrogen currently in use is so-called "gray hydrogen," which is produced from fossil fuels (mainly natural gas) and emits CO_2 into the atmosphere during the production process. In order to reduce CO_2 emissions associated with hydrogen production, the government plans to accelerate the expansion of the production capacity (in terms of the capacity of water electrolysis facilities) of "green hydrogen," which is produced using electricity derived from renewable energy sources. The target is to increase it from the current level of about 750 MW to 5 GW (equivalent to the energy output of five nuclear power plants, and capable of producing up to about 14 TWh of green hydrogen) in 2030, and then to more than 10 GW in 2040.

The government expects a global hydrogen supply market to be established by 2030, where "blue hydrogen" and "turquoise hydrogen," both carbon-neutral, will be traded. Whereas "Blue hydrogen" is produced from fossil fuels and "Turquoise hydrogen" is produced by pyrolysis of methane, both of their solid carbon generated in the process is captured and stored. Though Germany does not rule out the use of those hydrogen sources and take it as an interim period for energy transition, the government is determined Germany should specialize in CO_2-free green hydrogen in the medium to long term.

2.3 Initiatives to the practical application of green hydrogen technology

For the promotion of the practical use of hydrogen technology, the German Federal Ministry for Economic Affairs and Energy is primarily advancing the following three programs. (1) The HyExperts program forms concepts for green hydrogen utilization with high potential for practical use, and (2) the HyPerformer program supports the implementation of specific green hydrogen projects. Both programs promote the adoption of green hydrogen and fuel cell technologies by local governments under the framework of NIP II. In addition, (3) the Reallabor (Real-World Laboratories) program goes one step further and is working on large-scale hydrogen utilization experiments and their industrialization through industry-government-academia collaboration (Figure 3). In particular, large water electrolyzers, PtL equipment, heat pumps, smart grids, and district heating are targeted, and 600 million euros has been set aside for this program for 2020-2023.

Figure 3 The German Federal Ministry for Economic Affairs and Energy's hydrogen technology commercialization program — List of sites (as of December 2019)



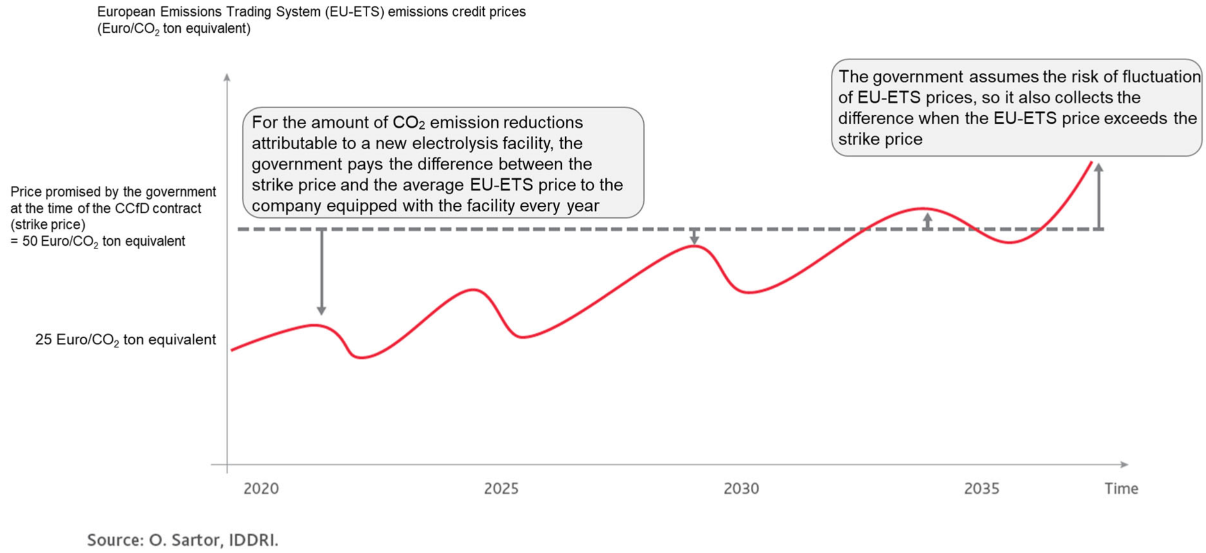
Source: TÜV SÜD (https://www.tuvsud.com/de-de/-/media/de/corporate/bilder/presse/2020/januar/20012_lbst_ptg-de-map_20191220_v2.jpg?la=de-de hash=4F756C88EAB62CD6F6DC84F7560DE682; reproduction of Ludwig-Bölkow-Systemtechnik (LBST) materials). Black circles are added by the author.

In the future, the government plans to expand the number of commercialization sites for each program throughout the country. Meanwhile, such sites have already begun to gather in four priority regions. The northern part of Germany, with its extensive low-lying areas, is expected to have the largest number of hydrogen production sites due to the high concentration of wind farms. Second to this is the German-Dutch economic zone, which includes the Ruhr area, the largest industrial cluster. In addition, the southwest part of Germany, which is adjacent to France, and the southern state of Bavaria, are also notable for the number of projects utilizing hydrogen technology, and are likely to become important locations for the hydrogen industry from now on.

2.4 Introduction of a differential payment trading system to guarantee CO_2 emission credits

Currently, the supply cost per unit of energy of green hydrogen is estimated to be more than four times that of natural gas and more than three times that of gray hydrogen. In this context, in order to promote the use of hydrogen (installation of electrolysis facilities to produce hydrogen) in energy-intensive industries such as steel and chemicals, the government is planning to launch a pilot program, Carbon Contracts for Difference (CCfD). This program is designed to guarantee the price under the EU Emissions Trading System for the CO_2 emission credits newly allocated for hydrogen use. As a risk hedge for new capital investment in electrolyzers and other equipment, CCfD function as a hedging instrument for future carbon prices; if the price of emission credits falls, due to market fluctuations below the price promised by the government at the time of the CCfD contract, the government pays the difference to the company concerned. Conversely, if the price of emission credits exceeds the price set at the time of the CCfD contract, the government has the right to receive the difference (Figure 4). The CCfD program will be used as a lever to encourage the active introduction of green hydrogen technology.

Figure 4 CfD mechanism (strike price and EU-ETS price are examples for reference)



Source: Institut du développement durable et des relations internationales (IDDRI) material https://www.iddri.org/sites/default/files/PDF/Publications/Catalogue%20Iddri/Etude/201910-ST0619-CCfDs_0.pdf). Annotations are by the author.

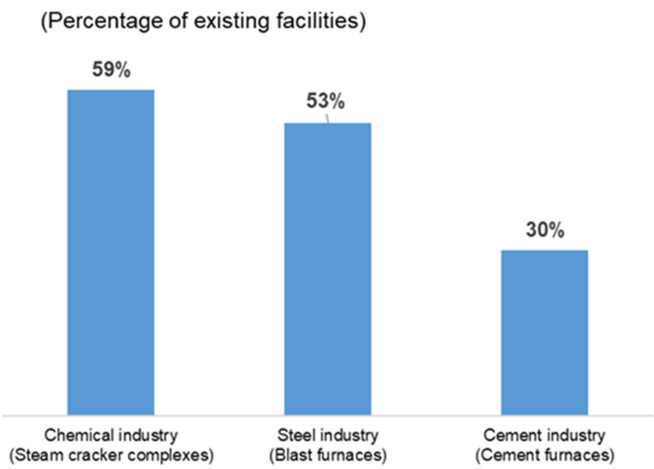
3. PROSPECTS FOR WIDESPREAD USE OF HYDROGEN TECHNOLOGY WITH REINVESTMENT IN INDUSTRIAL FACILITIES

3.1 Replacement of aging facilities in heavy industries presents a good opportunity to introduce hydrogen technology

Based on the premise that green hydrogen is the only sustainable energy source in the medium to long term, the German government emphasizes in its National Hydrogen Strategy the goal to work on the rapid creation of a market for green hydrogen and the establishment of the necessary value chain. During the first phase from 2020 to 2023, the government will give impetus to the development of the domestic hydrogen market and concentrate on the issues of promoting research and development and international cooperation. From 2024 to 2030, Germany plans to work on further growth of the domestic market and building an international supply network.

Between 2020 and 2030, Germany's heavy industry will enter a period where reinvestment to replace aging production facilities is necessary. According to the German Wuppertal Institute for Climate, Environment and Energy, which conducts research on sustainable economies and societies, Germany's top three greenhouse gas emitting industries in particular—the chemical (40.1% of total emissions in 2019), steel (35.6%), and cement (16.9%) industries—are under pressure to reinvest in key production facilities (Figure 5). In contrast, the lifespan of many of the new capital-intensive production facilities that will be built will exceed 30 years, and unless a switch is made to a new production process that uses hydrogen instead of fossil fuels, there is a significant risk of reinvestments turning into stranded assets. Leveraging the CCfD program and investment support for the use of hydrogen technology in large-scale facilities included in the National Hydrogen Strategy, the government sees the replacement of aging facilities as an opportunity to promote the introduction of hydrogen technology.

Figure 5 Major energy-intensive industries in Germany in which reinvestment in facilities is necessary due to aging (by 2030)



Note: Normally, steam cracker complexes are continuously maintained, and the entire facility is not replaced at once, and the degree of aging of the facility can be expressed by the ratio of reinvestment in the facility.
Source: Prepared by MGSSI, based on data from the Wuppertal Institute for Climate, Environment and Energy, Germany

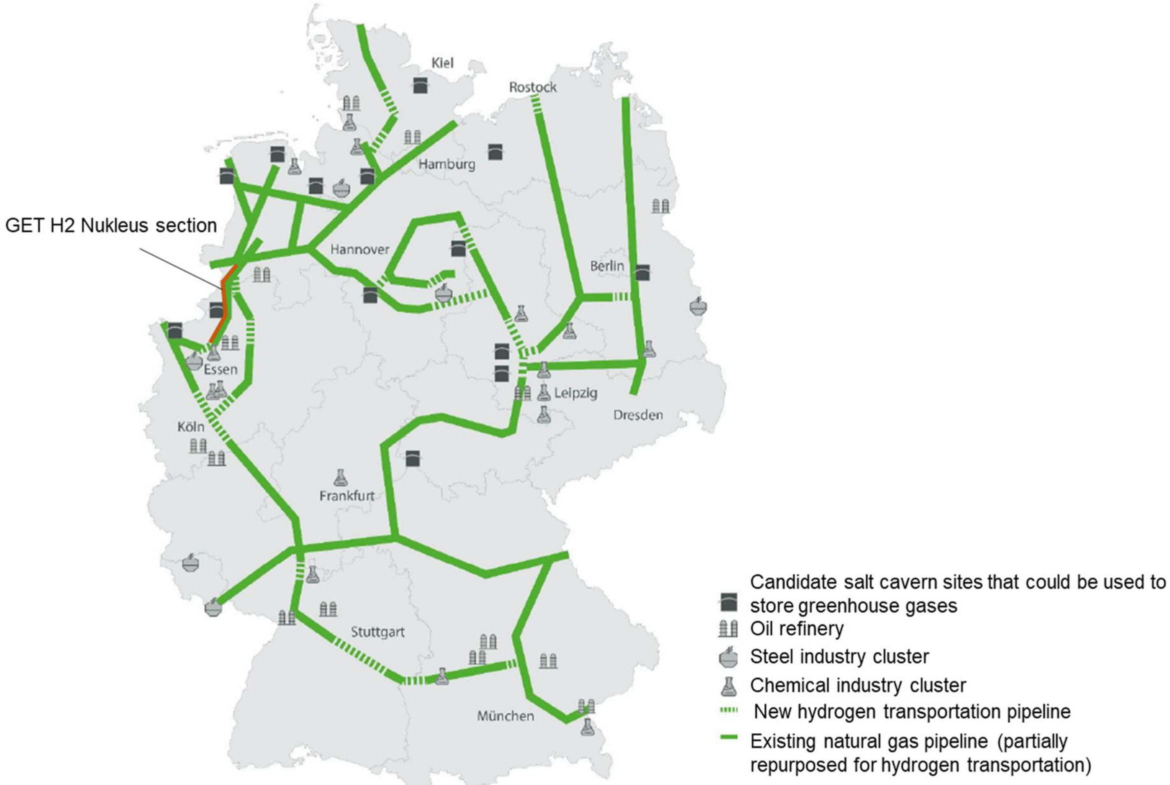
3.2 Growing demand for hydrogen makes PtG and PtL equipment sectors a promising export market

Germany's energy transition policy has made renewable energy the country's largest source of electricity (42.1% of total generation in 2019). However, when favorable weather conditions coincide with periods of low electricity demand, a large amount of surplus power is generated, and in 2019, about 6.3 TWh of wind power output (about 20% more than the previous year) was shut down by grid operators. For solutions to these problems, research and development in recent years have been actively pursuing technologies to convert and store surplus electricity as hydrogen, methane (PtG technology), and methanol (PtL technology) through water electrolysis. This trend is being boosted by the fact that many expect global hydrogen demand to grow significantly in the future. For example, Hydrogen Europe, an association established by 13 international energy, transportation, and manufacturing companies, estimates that by 2050, global demand for hydrogen will be 22,240 TWh, equivalent to 18% of global final energy demand (a 10-fold increase from 2015). The German government's forecast is also optimistic, looking to secure an export market for hydrogen technology, production machinery, and related equipment, as well as to increase demand. According to a survey by the German Economic Institute (IW), German companies such as ThyssenKrupp, Siemens, and Linde already account for about 20% of the world's exports of water electrolyzers, which are the core of PtG and PtL facilities. The export market for water electrolysis technology and equipment is regarded as promising, along with expectations for expansion.

3.3 Domestic hydrogen pipeline transportation plan

Hydrogen gas can be transported and stored using natural gas pipelines. In January 2020, FNB Gas, the association of German transmission system operators, announced plans for partially repurposing more than 90% of existing natural gas pipelines for hydrogen transportation and storage network (total length: 5,900 km) (Figure 6). Under the target of a stable supply to all of Germany, FNB aims to complete the plan by 2030. The operational policy also promises not to discriminate hydrogen based on its production location, and to handle not only green hydrogen from northeastern Germany, but also hydrogen imported via liquefied hydrogen carriers and pipelines. As an initial step in the plan, the power generator RWE Generation, transmission company Nowega, and energy and chemical giants OGE, Evonik, and BP began to develop a pipeline network (GET H2 Nukleus) in March 2020. This network will transport green hydrogen produced at RWE's 100 MW water electrolysis plant in the northern city of Lingen to BP's chemical plant in the Ruhr industrial zone near Essen and Evonik's chemical plant in the city of Marl, among other locations. The pipeline network that reaches out as far as 130 km is expected to begin transporting hydrogen by the end of 2022.

Figure 6 Germany's hydrogen network concept



Source: Data from FNB Gas, German association of transmission system operators (https://www.fnb-gas.de/media/fnb_gas_pi_veroeffentlichung_visionaere_h2-karte_1.pdf)
GET H2 Nukleus description added by author

4. INTERNATIONAL COLLABORATION TO SECURE HYDROGEN

Because the domestic production capacity for green hydrogen is limited, the German government expects that a large part of the future demand will be met by imports. To this end, it has recognized the expansion of international collaboration and cooperation as an important issue, and has positioned the Netherlands and France in particular as promising supply partners within the EU. Also, outside the EU, there are high expectations for the procurement potential of countries such as Morocco, Ukraine, and Russia.

4.1 Cooperation with the Netherlands is key to the National Hydrogen Strategy

The Netherlands is Europe's second largest natural gas producer after Norway, and its natural gas pipeline network connects with neighboring countries to form the backbone of the Northwest European energy infrastructure. However, Europe's largest Groningen gas field in the northern Netherlands will be shut down in 2022 due to frequent induced earthquakes. Therefore, in its hydrogen strategy announced in March 2020, the Dutch government set out the establishment of a core hydrogen hub in Europe, utilizing the existing natural gas network. Just before that, in January, joint efforts were launched by the German Federal Ministry for Economic Affairs and Energy, the Dutch Ministry of Economic Affairs and Climate Policy, and the German state of North Rhine-Westphalia, which contains the Ruhr industrial zone adjacent to the Netherlands. Under their HY3 project, the three parties are working to establish bilateral value chains for the production, transport, and industrial use of green hydrogen. Currently, a consortium including UK-Dutch Shell and the Dutch gas supplier Gasunie is promoting NorthH2, a large-scale green hydrogen production project that aims to supply 800,000 tons of hydrogen per year by 2040. A new offshore wind farm with the capacity of up to 10 GW will be used to produce hydrogen from desalinated seawater directly off the coast of the Netherlands in order to avoid electricity transmission losses to shore.

Collaboration and cooperation with France is also expected. In September 2020, the French government announced the details of its strategic plan for green hydrogen. A total of 7.2 billion euros will be invested by 2030, with the goal of replacing gray hydrogen use with green hydrogen in various industrial sectors. To this end, the country aims to install 6.5 GW of water electrolysis facilities and produce 600,000 tons of green hydrogen per year. France is focusing on creating a water electrolyzer manufacturing industry in cooperation with Germany, and is also examining the export of green hydrogen to Germany. However, since the electricity used is expected to come from nuclear power as well as renewable energy, it will be difficult for Germany, which is on a nuclear-free path, to import large quantities from France.

4.2 Plan to import hydrogen from outside the EU linked to the EU's hydrogen strategy

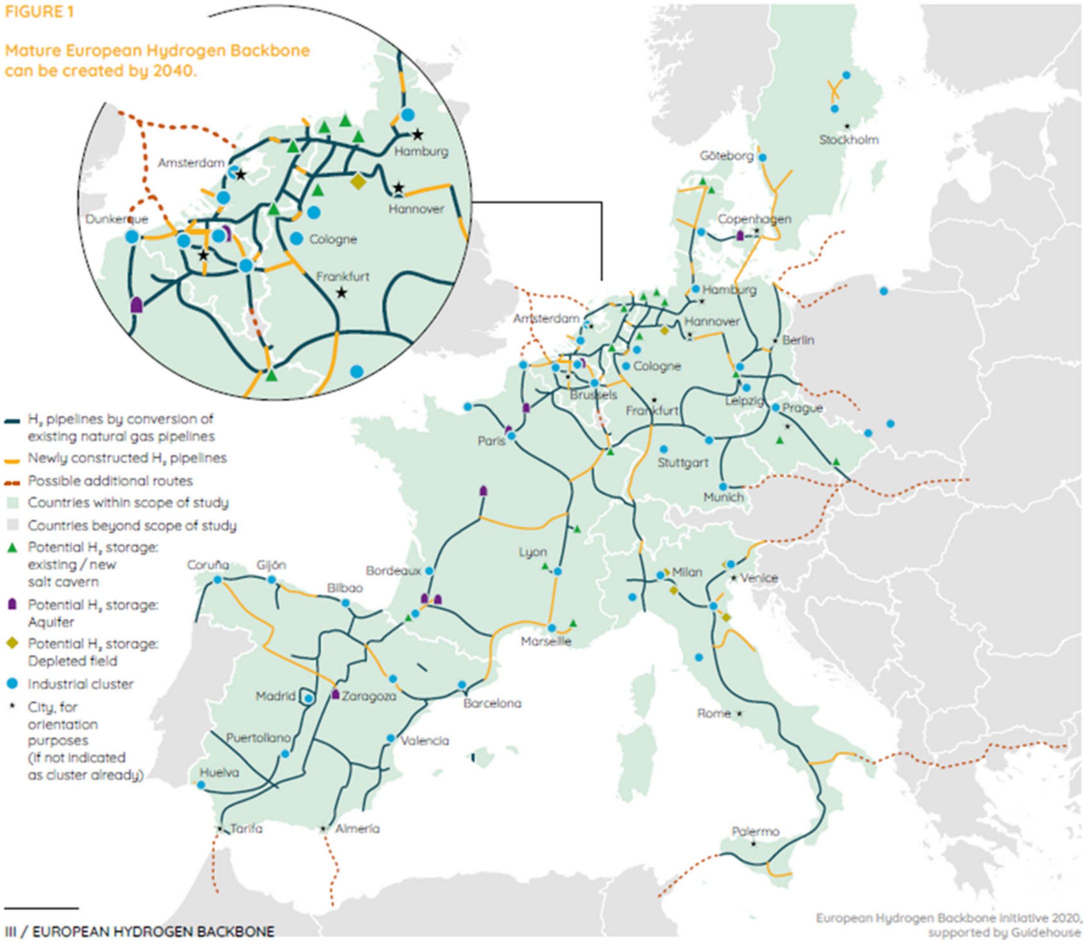
The focus is also on green hydrogen for securing hydrogen from outside the EU. In July 2020, the European Commission announced the EU's hydrogen strategy. As part of this strategy, the European Clean Hydrogen Alliance was launched with the participation of Hydrogen Europe and the European Investment Bank. The Alliance aims to spread the use of "clean" hydrogen, which has a different name from "green" hydrogen. Still, the Alliance stipulates that it will concentrate on the production of hydrogen derived from renewable energy sources. Its goal is to achieve a total of 40 GW of electrolyzer capacity in the EU and 40 GW in neighboring countries by 2030 (2x40 GW Green Hydrogen Initiative). Cooperation with this Alliance will be extremely important for Germany.

Germany's National Hydrogen Strategy does not specify from which EU neighboring countries/regions green hydrogen will be imported in the future. However, with "Shipping the sunshine" as its motto, it can be assumed that North Africa, which has much potential for solar power generation, is in mind. The EU's hydrogen strategy also expects procurement of price-competitive green hydrogen from the region to be possible in the future, and furthermore, has positioned efforts to develop a green hydrogen production environment in Ukraine as a priority. Against this backdrop, there is the vision of the 2x40 GW Green Hydrogen Initiative, which states that the solar power potential in North Africa and wind power potential in Ukraine should be utilized for green hydrogen.

Specifically, the plan is to convert 20 percent of the green hydrogen produced in the regions locally into ammonia, mainly for fertilizer, and export the remaining 80 percent (about 2.25 million tons per year from North Africa and about 750,000 tons per year from the Ukraine) to the EU. New pipelines are projected to transport hydrogen between Greece and Italy and between the Black Sea region and Greece by 2040, and these pipelines will be connected to the EU's existing natural gas pipeline network (Figure 7). To this end, immediately after the announcement of the National Hydrogen Strategy, the German government signed an agreement to provide a loan of 300 million euros for the construction of a new PtG facility (100 MW) in Morocco, and also issued a joint statement with Ukraine promising cooperation in the hydrogen sector.

It is also worth noting that high expectations have been placed on the procurement of green hydrogen from Russia. In July 2020, the Russian Ministry of Energy drew up a roadmap for hydrogen development until 2024, and the details are expected to be finalized by the end of 2020. There is a move to explore the possibility of using Nord Stream 2, a natural gas pipeline currently under construction, for the transport of hydrogen. In this regard, the German-Russian Resource Forum (a leading organization established by German and Russian universities to study close energy cooperation between Germany and Russia) inaugurated a working group in August to focus on hydrogen production and the construction of supply infrastructure. A hydrogen conference is also scheduled to be held in December with the participation of experts from industry, academia, and government from both countries.

Figure 7 Schematic diagram of the core pipeline network for hydrogen supply the EU plans to complete by 2040 (hydrogen backbone)



Source: Enagás, Energinet, Fluxys Belgium, Gasunie, GRTgaz, NET4GAS, OGE, ONTRAS, Snam, Swedegas, Teréga (editor) "European Hydrogen Backbone-How a Dedicated Hydrogen Infrastructure can be Created" (July 2020), Page 8 (https://gasforclimate2050.eu/sdm_downloads/european-hydrogen-backbone/)

5. FUTURE CHALLENGES AND PROSPECTS

The German government is accelerating public and private efforts to create a hydrogen society based on green hydrogen through its National Hydrogen Strategy. It thereby aims to strengthen its measures against climate change and become an international driving force for the use of hydrogen. In this context, the following four points in particular require careful attention.

(1) The National Hydrogen Strategy is a huge project worth just over 12 billion euros, but it is unclear whether the investment is sufficient to build a hydrogen society. The Future Package included in the new coronavirus economic stimulus package announced just before the release of the Hydrogen Strategy also sets aside a budget of seven billion euros for the launch of the green hydrogen market, but does not disclose specific measures. The Real-World Laboratories program has been working on large-scale hydrogen utilization experiments and their industrialization, but further expansion of the program was not included in the strategy. As pointed out by the leading independent German think tank LBST (specializing in future energy and transportation systems) and others, it will take time to set up a system for the mass production and mass utilization of green hydrogen, and the National Hydrogen Strategy, which only includes policies until 2026 at the longest, is just the first step to this end.

(2) The cost competitiveness of green hydrogen is a major issue. Depending on the price of renewable energy-derived electricity, the cost competitiveness of green hydrogen is low, and its price is estimated to be three

times higher than that of gray hydrogen. Therefore, it will be difficult to achieve smooth social penetration of hydrogen unless the use of blue hydrogen (the price of which is about half that of green hydrogen) and turquoise hydrogen are also actively promoted. An analysis by the Institute for Energy Economics (EWI) at the University of Cologne in Germany concluded the same. Although the government has stated that it will not rule out the use of blue and turquoise hydrogen for the time being, all measures in the National Hydrogen Strategy are dedicated to green hydrogen, and a more flexible policy seems essential.

(3) The development of hydrogen import infrastructure, especially from North Africa and Ukraine, is a difficult task. Germany will need to actively work with the EU on this. Many experts question the feasibility of exporting large quantities of hydrogen produced by electrolysis from North African countries, where population growth rates remain high and electricity demand is expected to continue to grow. Added to this is geopolitical risk. Since 2009, a consortium led by a German company had been working on the large-scale Desertec initiative to transport renewable energy-derived electricity produced in North Africa to Europe, but as demand for electricity in the region increased, there was growing concern about securing export volumes. The Arab Spring, which took place between 2010 and 2012, reaffirmed the geopolitical risks in the region, and as a result, Desertec was abandoned in 2014.

(4) There is also a high political risk in Ukraine, which has tense relations with Russia, and there are many who question the likelihood of steady supply from that country. Meanwhile, the German-Russian Resource Forum has begun research on repurposing the Nord Stream 2 pipeline under construction to also export green hydrogen from Russia to Germany. The US has imposed sanctions on Russia over concerns that the pipeline will increase Russia's control over Europe's energy supply, but the pipeline is expected to be completed in 2020. In the future, as the Russian government promotes hydrogen development, which it considers an important issue, Germany is likely to become an important export destination for Russian hydrogen (including green hydrogen, which is mainly produced by hydroelectric power).

Although there are many issues to be addressed, Germany is taking concrete steps toward the realization of a hydrogen society. The government is anticipating the establishment of a global hydrogen supply market by 2030, and the future of these measures as a driving force will be closely watched.