Germany's National Hydrogen Strategy toward Acceleration of the Energy Transition

Tomoko Matsumoto*

Summary

Germany is committed to an energy transition which facilitates a more efficient energy system and shifts from fossil fuels and nuclear power to renewable energy. Germany's long-awaited *National Hydrogen Strategy* was published on June 10, 2020. Hydrogen is expected as a crucial technology which will enable Germany to decarbonize the economy and accelerate the energy transition.

This was not a surprise beyond our expectations as some principles were reported by media before the official publication. Still, it is important to point out three issues as vital aspects of the strategy: first, blue hydrogen is allowed as a transitional technology although only green hydrogen is considered to be sustainable in the long-term; second, hydrogen import is expected to meet domestic demand in the future; and third, the State Secretaries' Committee on Hydrogen and the National Hydrogen Council are established for effective governance to implement the strategy.

The National Hydrogen Strategy is considered in two phases until 2030. In the first phase to 2023, the hydrogen market will be ratcheted up and a basis for domestic demand will be established. In parallel, fundamental measures such as research and development (R&D) will be undertaken. The second phase from 2024 to 2030 blueprints that the domestic hydrogen market will get on the right track, the European and international dimensions of hydrogen will be set, and the German industry will take this opportunity. There are 38 measures proposed in the strategy from the hydrogen supply chain to international cooperation for the first phase.

Germany's support for hydrogen deployment centers on R&D in the field of fuel cell and hydrogen technologies, even before hydrogen gains momentum, and has recently focused on more large-scale demonstration projects. There are also programs to develop the hydrogen refueling station network and introduce hydrogen fuel cell technology in municipalities and regions. Germany leads the world in the Power-to-Gas projects as they have increased in number and scale and are conducted in various sectors.

That the Federal Government showed approaches for hydrogen deployment and clarified the support for technology innovation will stimulate private investment in hydrogen technology. Taking the possibility of hydrogen imports into consideration, the Federal Government will establish and strengthen partnerships with countries which envisage hydrogen exports.

Introduction

Germany's long-awaited *National Hydrogen Strategy* went public on June 10, 2020.[1] It was not a surprise beyond our expectations as some principles were reported by media in early 2020 when a draft was circulated among ministries. Still, it is worthwhile to pay attention to the strategy to better understand how Germany approaches hydrogen energy in domestic and international markets.

Germany is committed to an energy transition which facilitates a more efficient energy system and shifts from fossil fuels and nuclear power to renewable energy. With the purpose of improving energy security, environmental sustainability, and economic efficiency, Germany has set out measures to increase renewable energy consumption and energy efficiency in order to achieve the energy transition target such as a reduction of greenhouse gas emissions of 55% by 2030 compared to the 1990 level and an expansion of the share of renewable sources in power generation to 65% by 2030. Renewable energy sources have steadily increased in power generation. However, the rapid growth of renewable energy has made it difficult to maintain the power grid because areas with abundant renewable energy sources are distant from the region where electricity demand is high, i.e., most wind power is installed in the north whereas the industry is more active in the south and west. In addition, the industry and transport sectors have struggled to make progress in decarbonization, which makes it seem difficult to achieve the 2030 target. Hence, hydrogen is expected as a crucial technology which will enable Germany to decarbonize the economy and facilitate the energy transition.

This report first sheds light on the important issues that require attention in the strategy and succinctly describes the goals and the action plans of the strategy. Then, some essential measures that Germany has implemented are presented to show the country's efforts to develop hydrogen industry/society. Several demonstration cases of Power-to-Gas (PtG) are also illustrated as Germany is the pioneer of PtG applications.

1. Germany's National Hydrogen Strategy

The *National Hydrogen Strategy*, whose publication was initially planned in 2019, came to light in June 2020. Disagreement among the ministries on targets of green hydrogen[2] production and the extent to which blue hydrogen should be used as a bridging technology seemed to delay the finalization of the strategy.[3] The strategy finally revealed how Germany encourages hydrogen development and explores international cooperation regarding hydrogen, as well as action plans

*Senior Researcher, New and Renewable Energy Group, Electric Power Industry & New and Renewable Energy Unit, the Institute of Energy Economics, Japan

[1] The Federal Government (2020). *The National Hydrogen Strategy*. Berlin/ Federal Ministry for Economic Affairs and Energy (BMWi)

[2] There are different names for hydrogen by color which are customarily used, based on how it is produced. Green hydrogen is produced through electrolysis, a chemical process to extract hydrogen from water using renewable power. Grey hydrogen is extracted from fossil fuels such as natural gas and coal whereas blue hydrogen is the same as grey hydrogen but carbon capture and storage (CCS) technology is involved in the production process to reduce CO_2 emissions. Turquoise hydrogen is produced through methane pyrolysis.

[3] Amelang, S. (May 18, 2020) "Merkel's coalition partner pushes for ambitious green hydrogen production" *Clean Energy Wire*

in the hydrogen supply chain from production through transport to various applications. The strategy is a milestone that Germany pursues to lead the world in the field of hydrogen technology.

1-1 Key issues of the National Hydrogen Strategy

The media revealed some primary schemes of the National Hydrogen Strategy before it was officially approved. Nevertheless, it is important to grasp the fundamental policy direction of the strategy. This section presents the following three issues as vital aspects of the strategy: first, blue hydrogen is allowed as a transitional technology; second, hydrogen import is expected to meet domestic demand in the future; and third, the State Secretaries' Committee on Hydrogen and the National Hydrogen Council are established for effective governance to implement the strategy.

(1) Green hydrogen vs. blue hydrogen

The National Hydrogen Strategy clarifies Germany's position to prioritize green hydrogen. As only green hydrogen is regarded as sustainable in the long term, the Federal Government aims to accelerate its deployment and establish the necessary value chains. Carbon-free hydrogen including blue hydrogen and turquoise hydrogen is likely to be traded in global and European markets to be developed in the coming decade. Germany acknowledges that carbon-free hydrogen needs to be utilized as a transitional means until green hydrogen is supplied to meet demand at an affordable price. In Germany, opposition to the use of fossil fuels is intense due to the environmental impacts and it is difficult for CCS to receive public acceptance because concerns on the possibility of CO_2 leakage are never be cleared. Such public resistance to CO_2 emissions stood in a way that blue hydrogen production was put on the table. However, Germany compromised and accepted carbon-free hydrogen in the strategy probably because hydrogen deployment needs to be prioritized to accelerate decarbonization against climate change. One condition attached is that blue hydrogen should not be produced domestically and only that imported will be allowed.

(2) Electrolysis capacity target and hydrogen import

It is necessary to develop a robust and sustainable domestic market in hydrogen production and application in the initial phase of market development with regard to hydrogen technologies. Demand for hydrogen is currently 55TWh (approximately 1.38 million tons) in Germany, of which green hydrogen accounts for merely 7% (3.85TWh, about 96,000 tons). The Federal Government has extensively supported research and development (R&D) on hydrogen technology. In addition, on June 3, 2020, the government coalition adopted a €130 billion stimulus package for 2020-2021 to recover from the COVID-19 pandemic and €7 billion out of the package is spared for accelerating hydrogen technology development.[4]

The target of electrolysis capacity, which was an issue that the relevant ministries found difficult to reach agreement on, is set at 5GW by 2030 and a further 5GW will be added by 2030 if possible and no later than 2040. The electrolysis capacity of 5GW provides hydrogen

[4] Wehrmann, B. and Wettengel, J. (June 4, 2020). "German gives energy transition mild boost with economic stimulus program." *Clean Energy Wire*

production of 14TWh (about 350,000 tons)[5]. While hydrogen demand is estimated to reach 90-110TWh (about 2.25 million tons to 2.75 million tons) by 2030, the domestic supply of green hydrogen is not likely to meet the demand sufficiently. Therefore, Germany anticipates that hydrogen will need to be imported. To this end, the country aims to strengthen international cooperation and partnerships. Since there are great potentials for green hydrogen production found in some EU member countries such as offshore wind power in the North and Baltic Sea and solar energy in southern Europe, Germany needs to foster cooperative relationships with the EU members. Germany will also plan green hydrogen production projects in partner countries as a part of development cooperation. €2 billion of the stimulus package is appropriated to support such hydrogen production projects in partner countries.

(3) A flexible and results-oriented governance framework

To implement the National Hydrogen Strategy effectively, a State Secretaries' Committee on Hydrogen with which relevant ministries are involved will be established. This Committee takes corrective measures in cooperation with the Federal Cabinet in case the actions required to carry out the strategy are delayed or it is foreseeable that the targets will be missed.

The National Hydrogen Council also plays a critical role to provide the Committee with the necessary support and advice in implementation of the strategy. This Council is composed of 26 high-level experts from business, science, and civil society who will be appointed by the Federal Government. Designated representatives at the Director-General level of the relevant ministries take part in the Council as guest, as do two delegates of Länder (the local government at state level in Germany) at the request of the Länder. The Council is held at least twice a year and has a joint meeting regularly with the Committee on Hydrogen to facilitate coordination.

In addition, the Hydrogen Coordination Office in association with the National Hydrogen Council will be organized to assist the relevant ministries in exercising necessary measures for the strategy and the Council in coordination and drafting recommendations. The Hydrogen Coordination Office is in charge of monitoring the implementation of the strategy and submitting an annual monitoring report to the Committee and the Council. Based on the annual monitoring reports, an extensive report will be made every three years, which will include evaluation of progress of the strategy and the action plans and make suggestions on necessary remedial measures. Accordingly, the strategy will be ensured to be consistent with market development and the targets to be achieved.

1-2 Goals and ambitions of the National Hydrogen Strategy

The National Hydrogen Strategy provides a crucial framework to build up the necessary hydrogen supply chain and encourages technology innovation and private investment. The strategy is also expected to help Germany to meet the climate targets, create new value chains for the economy, and to promote international cooperation in energy policy. The strategy raises the goals and ambitions as follows:

[5] 4,000 full-load hours of electrolyzer operation is assumed.

- To take responsibility for greenhouse gas emission reductions globally
- To reduce the cost of hydrogen technology and make it competitive
- To develop a domestic market for hydrogen technology, paving the way for hydrogen imports
- To ensure hydrogen as an enabling energy source for decarbonization
- To make hydrogen a sustainable input for the industry sector
- To develop hydrogen transport and distribution infrastructure in the regulatory framework and technical requirements to enhance safety of hydrogen use
- To facilitate appropriate capacity development and set up new research institutes
- To create the energy transition process to which hydrogen technology contributes
- To strengthen the German industry by means of the hydrogen technology and provide global market opportunities for German companies
- To develop international hydrogen markets and establish international cooperation on hydrogen with the prospect of turning into a hydrogen import country
- To promote international cooperation that benefits the partner countries for climate change mitigation and sustainable development, taking advantage of heightened momentum around hydrogen
- To secure quality assurance for hydrogen production, transport, storage and use, and build trust for the users
- To review the progress of the strategy on regular basis and consider the further development including necessary measures

1-3 Action plans to develop the hydrogen supply chain

The measures of the action plans listed in the National Hydrogen Strategy are considered in two phases until 2030. In the first phase to 2023, the hydrogen market will be ratcheted up and a basis for domestic demand will be established. In parallel, the fundamental measures such as R&D will be undertaken. The second phase from 2024 to 2030 blueprints that the domestic hydrogen market will get on the right track, the European and international dimensions of hydrogen will be set, and the German industry will take this opportunity. With expectations toward the strategy which will encourage private investment and stimulate the economy to recover from the COVID-19 pandemic, there are 38 measures proposed in the strategy from the hydrogen supply chain to international cooperation for the first phase. These action plans aim to develop a framework for the supply chain and expedite technology innovation and investments. The relevant ministries are responsible for implementing and financing the measures. Among others, some important measures are outlined below.

(1) Hydrogen production

It is critical to scale up the production capacity to bring down the hydrogen production costs. Preferential tax treatment for electricity used to produce green hydrogen (e.g., exemption of green hydrogen production from the EEG[6] surcharge) and funding for investments in electrolyzers are

[6] Renewable Energy Source Act (Erneuerbare Energien Gesetz)

raised as measures to assist hydrogen production. Regarding offshore wind as a promising technology to produce green hydrogen, the strategy also indicates the necessity to develop a framework that will encourage investment in offshore wind energy.

(2) Hydrogen application

To facilitate hydrogen use in practice, the strategy focuses on the applications that are to reach economic feasibility in the short- or medium-term, or that are difficult to find alternative options for decarbonization for the measures to be taken.

In the transport sector, the use of green hydrogen as an alternative to conventional fuels will be incorporated into a domestic law which reflects the EU Renewable Energy Directive (RED II). One of the schemes in discussion is that the aviation industry which heavily depends on petroleum products may be required to use electricity-based jet fuel at a minimum quota of 2% by 2030. Funding from the Energy and Climate Fund will also be available to increase investments in fuel cell vehicles until 2023.[7] Specifically, the fund prepares €3.6 billion for clean energy vehicles including fuel cell vehicles, €1.1 billion for installations for the production of synthetic fuels, and €3.4 billion for the construction of a refueling and charging infrastructure. Since the Federal Government promotes the use of green hydrogen in commercial vehicles such as heavy-duty road haulage, the network of refueling stations needs to be developed quickly.

Hydrogen rollout is expected to speed up in the industry sector. Grey hydrogen is possibly replaced by green hydrogen in the chemical industry or refineries while pilot projects testing hydrogen reduction of iron ore are already being attempted in the steel industry. The Federal Government will render a pilot program of Carbon Contract for Difference (CfD) in the steel and chemical industries. This program will compensate for the difference between the actual cost of avoided emissions based on a contractually agreed carbon price per amount of GHG emissions prevented and the prices of the Emissions Trading System (ETS). If the ETS price is above the carbon price agreed contractually, the difference exceeding the agreed price above needs to be paid back to the government. The strategy also will develop hydrogen-based long-term decarbonization strategies with stakeholders, which will start with energy intensive industries such as the chemical, steel, logistics and aviation sectors.

(3) Heat supply

Even after energy efficiency and electrification are utilized in the heat supply process or in buildings, there is room for hydrogen and synthetic fuels to contribute to decarbonization. The Energy Efficiency Incentive Programme which has been put in place since 2016 will be continuously used for funding to support highly efficient fuel cell heating systems.[8]

[7] The Energy and Climate Fund was established in 2011 to implement the energy shift and funding is provided annually (€4.5 billion in 2019). The funding is available for measures such as investments in energy efficiency including building modernization, renewable energy, and energy storage.
(The Federal Government (March 12, 2019). “More money for the energy shift”
https://www.bundesregierung.de/breg-en/service/more-money-for-the-energy-shift-1589036)

[8] The Energy Efficiency Incentive Programme provides support measures to modernize heating and ventilation systems to improve energy efficiency and the energy transition in the building sector.
(BMWi. “Energy Efficiency Incentive Programme - Targeted funding for more investment in comfort and efficient

(4) Hydrogen supply infrastructure

Hydrogen supply systems that are secure, reliable, and demand-based will be important in the future hydrogen market. While it is an option to transport hydrogen using the existing gas infrastructure, development of transport infrastructure dedicated to hydrogen is necessary to be considered as swiftly as possible. When it comes to the transport of hydrogen in the international market, hydrogen needs to be liquefied, or transported as liquid organic hydrogen carriers, ammonia or methane. It is urgently important to take on developing the regulatory framework for construction and expansion of the hydrogen infrastructure. Sector coupling connecting electricity, heat, and gas also necessitates further facilitation for the energy transition. If a network of hydrogen refueling stations is newly planned, it requires deliberate coordination among road transport at suitable locations, the railway network, and the waterways.

(5) Research, education and innovation

Germany aims to lead the global market of green hydrogen technology. A roadmap for the German hydrogen industry will be developed as guidance to achieve the purpose. Demonstration projects regarding green hydrogen will be conducted in the short-term. Under the new initiative of "hydrogen technologies 2030," some research activities in the area of key hydrogen technologies are bundled for strategic implementation. In addition, from 2020 to 2024, a total of €25 million from the Aviation Research Programme and a portion of approximately €25 million of the Maritime Research Programme are allocated to work related to hydrogen technology in the aviation and marine industry, respectively.

(6) Necessary actions at European level

Germany sees the EU Council Presidency for the last half of 2020 as an opportunity to promote hydrogen in preparation for the legislative package on sector coupling and gas market design. Development of a robust market in which hydrogen can contribute to the energy transition and decarbonization and boosts export opportunities for German and European companies requires sustainability standards, high quality infrastructure, and proof of origin for electricity from renewable energy and for green hydrogen. Furthermore, setting up the international hydrogen market entails sustainability and quality standards at the European level with regard to hydrogen and Power to X, a concept of converting electricity through green hydrogen or synthetic methane to other energy carriers such as liquid fuels, power, and heat. At the EU level, approval as Important Project of Common European Interest (IPCEI)[9] may work to encourage investments in research, development and demonstration of green hydrogen technology. Hence, the Federal Government has proactively approached the European Commission and other member states to

heating in the home"
https://www.bmwi.de/Redaktion/EN/Dossier/enhancing-energy-efficiency-in-buildings.html)

[9] State aid which is financial assistance given to companies or organizations with the potential to distort market competition is prohibited under EU rules. If a project is to be qualified for approval from the European Commission under the IPCEI framework, certain criteria set out in the IPCEI Communication need to be fulfilled, for instance, that the project is jointly supported by several member states and contributes to economic growth, job opportunities and competitiveness across Europe.

initiate a joint project that will qualify for the IPCEI.

(7) International hydrogen market and partnership

As a new prospect of international cooperation on hydrogen, Germany provides partner countries with German hydrogen technology, which will help them to produce hydrogen from renewable energies or fossil fuels and consequently export it to Germany as well as to reduce dependence on fossil fuels. With this type of partnerships established, Germany will be able to import hydrogen while fossil fuel exporting countries will turn to hydrogen producing and exporting countries and achieve decarbonization and economic growth with less use of fossil fuels. It is obvious that Germany will strengthen the existing international framework and partnership to see the global trend of hydrogen and obtain information to identify potential partner countries.

2. Germany's approach to support hydrogen applications

In Germany, renewable energy has been steadily expanding its share in the power sector, which helps to decarbonize the sector as intended, whereas the other industries, the transport sector, and buildings have struggled to improve energy efficiency and facilitate decarbonization, failing to fulfill the targets. A distinctive aspect of Germany's energy demand is that heating accounts for more than half of the final energy consumption. This fact implies that it is key to decarbonize the heating supply systems for the buildings and the industry sector in order to succeed in the energy transition. Given the difficulty to reduce GHG emissions in these sectors, carbon-neutral hydrogen and synthetic fuels are expected to decarbonize the sectors in which there is no alternative technology available. The 2030 Climate Action Programme adopted in September 2019 points out a vital role of hydrogen in R&D.[10] This chapter seeks how Germany has supported hydrogen development.

2-1 Policy measures to encourage hydrogen deployment

2-1-1 Support for research, development, and demonstration

Germany is one of the countries that have recognized the potential of fuel cell and hydrogen technologies even before hydrogen gains momentum. Germany has provided support primarily for R&D in the field of fuel cell and hydrogen technologies through the Energy Research Programme since 1977. Under the 7th Energy Research Programme for 2018-2022, the Federal Government provides €6.4 billion for research, development and demonstration (RD&D), which is a 45% increase from the 6th program for 2013-2017.[11] The 7th Energy Research Programme broadens the scope of funding, covering not only individual technologies but also cross-cutting topics which are important in restructuring the energy system. In addition to digitalization and the energy transition, sector coupling is especially focused on as it will enable renewable energies to be used efficiently in transport and the heating/cooling systems of the industry and building

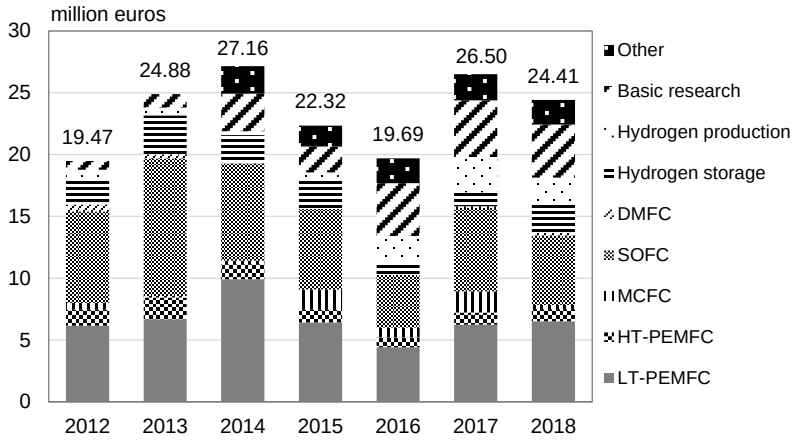
[10] The Federal Government (September 20, 2019). "Climate Action Programme 2030" (https://www.bundesregierung.de/breg-en/issues/climate-action/klimaschutzprogramm-2030-1674080)
[11] BMWi (2018). *Innovations for the Energy Transition – 7th Energy Research Programme of the Federal Government*. Berlin/BMWi. p.8

sectors. Encouraging further utilization of green hydrogen and synthetic fuels in these sectors will be a challenging issue.

The 7th Energy Research Programme adds an important role to support large-scale field testing (a term of '*Reallabor*' in German is used to describe it and it means 'real-environment laboratory').[12] On July 2019, the Federal Ministry for Economic Affairs and Energy (BMWi) announced the winners of the competitive bidding of "Real Laboratories for the Energy Transition (*Reallabore der Energiewende*)" and awarded them €100 million annually.[13] The selected 20 projects plan to examine low-carbon hydrogen technologies regarding production, transport, or utilization at industry scale. These demonstration projects are expected to offer necessary data and information to utilize the new hydrogen technologies in practice and identify possible impacts on the energy system or the energy transition. They will also help to develop the necessary regulatory framework to make a competitive business model in the long-term.

The actual outlays of the project funding for fuel cells and hydrogen technology provided by the Federal Government maintain an amount of around €20 million and it was €24.41 million in 2018 (Figure 2-1). The funding was centered on fuel cell technologies early on, but it has been allocated more to the projects on hydrogen production or storage technologies lately.

Fig. 2-1 Actual outlays of the project funding for fuel cells and hydrogen technology



Note: LT-PEMFC = low-temperature proton exchange membrane fuel cell, HT-PEMFC = high-temperature proton exchange membrane fuel cell, MCFC = molten-carbonate fuel cell, SOFC = solid oxide fuel cell, DMFC = direct methanol fuel cell

Source: BMWi (2019)[14]

[12] Jensterle, M. et al. (2019). *The role of clean hydrogen in the future energy systems of Japan and Germany*. Berlin/Adelphi. p.14

[13] BMWi (July 18, 2019). "Altmaier verkündet Gewinner im Ideenwettbewerb ‚Reallabore der Energiewende': „Wir wollen bei Wasserstofftechnologien die Nummer 1 in der Welt werden"." (https://www.bmwi.de/Redaktion/DE/Pressemitteilungen/2019/20190718-altmaier-verkuendet-gewinner-im-ideenwettbewerb-reallabore-der-energiewende.html)

[14] BMWi (2019). *2019 Federal Government Report on Energy Research – Funding research for the energy transition*. Berlin/ BMWi. Table 2 (pp.57-58).

2-1-2 NOW's assistance for hydrogen and fuel cell technology development

The National Organisation of Hydrogen and Fuel Cell Technology (NOW) plays the major role in hydrogen and fuel cell technology development in Germany. NOW facilitates collaboration among the government, industry and academia and coordinates activities in national and international frameworks.[15] As one of the major tasks, NOW oversees the National Innovation Programme Hydrogen and Fuel Cell Technology (NIP), which aims to enable hydrogen and fuel cell technology to enter the market and make them competitive globally. To this end, NOW supports innovation of fuel cell technology and development of a hydrogen refueling station network. The Federal Government funded around €700 million between 2006 and 2016 and approved a total of €1.4 billion in funding between 2016 and 2026 under the NIP.[16] In the second phase, the Federal Government provides support to the products that are not competitive yet in the market for market entry.[17] There are two programmes, namely H2 MOBILITY and HyLand, supported by NOW under the NIP framework.

(1) H2 MOBILITY

NOW assists the development of a hydrogen refueling station network in Germany.[18] Within the term of NIP, NOW supports H2 MOBILITY, the joint venture H2 MOBILITY Deutschland GmbH & Co.KG. established by six companies - Air Liquide, Daimler, Linde, OMV, Shell, and Total – in 2015 and a partnership to establish a nationwide infrastructure for hydrogen mobility. H2 MOBILITY pursues building up to 10 stations each in six major regions – Hamburg, Berlin, Rhine-Ruhr, Frankfurt, Stuttgart, and Munich along with the hydrogen corridor. This partnership is also supported by the Fuel Cells and Hydrogen 2 Joint Undertaking (FCH 2 JU) of the European Commission.

(2) HyLand - Hydrogen regions in Germany

NOW introduced a new funding program called 'HyLand - Hydrogen regions in Germany' to support municipalities and regions for green hydrogen deployment under the NIP in 2018. It is necessary to incorporate deployment of green hydrogen into regional development planning in order to achieve the nation's goal of CO_2 reductions. The program intends to assist the municipalities and regions to conceptualize initial ideas or make plans more concrete so that the plan would be carried out. Since each municipality and region has a different basis on green hydrogen deployment, this program is grouped into three categories; 'HyStarter' for awareness improvement or an initial phase organization, 'HyExperts' for developing integrated concepts and in-depth analysis, and 'HyPerformer' for taking steps to procure actual applications and implementing the concepts.[19]

[15] Jensterle, M. et al. (2019). *op.cit.* pp.14-15
[16] The Federal Government (2020). *op.cit.* p.3
[17] NOW. "NIP Funding Programme" (https://www.now-gmbh.de/en/national-innovation-programme/funding-programme)
[18] NOW. "Development of a hydrogen refuelling station network" (https://www.now-gmbh.de/en/national-innovation-programme/aufbau-wasserstoff-tankstellennetz)
[19] NOW. "HyLand- Hydrogen regions in Germany" (ttps://www.now-gmbh.de/en/national-innovation-

The municipalities and regions to be qualified for this federal aid measure need to go through a competition process. For 'HyStarter,' nine regions in seven categories were chosen as winners out of 85 applications submitted in September 2019. Those nine regions receive advice for about two years on the joint development of initial concepts on subjects of hydrogen and fuel cells in the areas of transport, heat, electricity, and storage systems. Subsequently, thirteen regions of 'HyExpert' and three regions of 'HyPerformer' were selected in December 2019.[20] Funding of €300,000 is provided to each HyExpert to develop feasible project plans for hydrogen concepts and €20 million to each HyPerformer in the form of investment grants for the implementation of existing concepts.

2-2 Overview of hydrogen applications in Germany

2-2-1 Current situations of hydrogen deployment by sector

This part briefly reviews the current situations of hydrogen use in Germany. In practice, grey hydrogen produced from fossil fuels has been utilized mainly in the industrial process in Germany as it is in Japan. Yet, there are various PtG demonstration projects using renewable energy as described in the next subsection.

Industry sector: Approximately three-quarters of hydrogen is produced and used in refineries and chemical industry in Germany.[21] Hydrogen application is a critical technology to reduce CO_2 emissions in the industry sector facing difficulty for decarbonization. Hence, PtG demonstration projects are expected to prove this potential.

Transport sector: Deployment of fuel cell vehicles (FCV) has been encouraged in the transport sector. As of October 2019, there are 530 FCVs, 21 FC buses, 2 FC trucks, and 100 FC forklifts.[22] Infrastructure development required to promote FCV deployment has steadily made progress, as well. As of June 2020, 84 hydrogen refueling stations are in operation, and 21 more stations are underway.[23] Therefore, the target of developing 100 hydrogen refueling stations by 2020 is likely to be achieved. In September 2018, a breakthrough happened in the transport sector. That is, the trial operation of the world's first passenger train powered by a hydrogen fuel cell rolled out in Lower Saxony.[24] The two hydrogen trains were operated on the 100 km route between the cities of Cuxhaven and Buxtehude and this trial was successfully completed at the end of February 2020. Along with a hydrogen refueling station to be built near Bremervoerde

programme/hydrogen-regions-in-germany)

[20] NOW (September 9, 2019). "HyStarter competition: nine regions win hydrogen region status" (https://www.now-gmbh.de/en/news/press/hystarter-competition-nine-regions-win-hydrogen-region-status)
NOW (December 11, 2019). "Germany on its way to becoming a hydrogen country: Another 16 regions receive support for H2 projects" (https://www.now-gmbh.de/en/news/press/germany-on-its-way-to-becoming-a-hydrogen-country)

[21] Jensterle, M. et al. (2019). *op.cit.* p.6

[22] International Partnership for Hydrogen and Fuel Cells in the Economy (IPHE). "Germany" (https://www.iphe.net/germany)

[23] H2.LIVE. https://h2.live/en/

[24] Alstom (May 19, 2020). "Successful year and a half of trial operation of the world's first two hydrogen trains, next project phase begins" (https://www.alstom.com/press-releases-news/2020/5/successful-year-and-half-trial-operation-worlds-first-two-hydrogen)

station, 14 hydrogen powered trains will replace the existing diesel units in 2022.

Residential sector: Mini- and micro- cogeneration systems with a fuel cell are available in Germany as the ENE-FARMs are in Japan. There are 6,600 units of CHPs installed as of October 2019.[25] The apartment complex-scale systems which produce hydrogen from extra renewable power, store and use it in a fuel cell-based CHP system or combust it in a boiler have already been introduced to improve energy efficiency and reduce CO_2 emissions in the building.[26] Hydrogen can be also stored in the form of synthesis gas.

Power sector: Fuel cell-based UPS (uninterruptible power supply) systems are utilized as back-up power supply in Germany although they are not very popular in Japan. Also, research on hydrogen combustion in a gas turbine has been in progress. Currently, a fuel mix with up to 60% hydrogen content is operable and the development of turbines allowing pure hydrogen is expected in the future.[27]

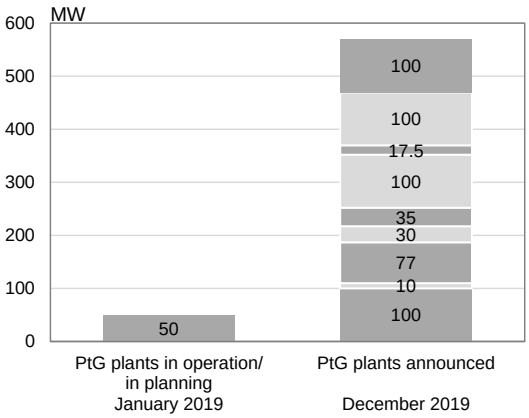
2-2-2 Demonstration projects in Power to Gas (PtG)

Germany is leading the world in PtG which converts renewable electricity through an electrolyzer to hydrogen or, by subsequent synthesis, to methane, which can be transported in the existing infrastructure and utilized in different sectors. The German Energy Agency (DENA) set up the PtG strategy platform (Strategieplattform Power to Gas) in 2011 to advance technology development and market uptake of PtG.[28] Approximately 30 companies participate in this platform to commercialize PtG and develop the market, which will lead to the establishment of business models and achievement of economy of scale. The PtG projects have steadily increased and, as of June 2020, 68 projects from planning to commercialization phases are identified in the platform. Some of them are also large-scale projects funded by the 7th Energy Research Programme.

The year of 2019 witnessed a robust increase in the PtG projects. At the beginning of the year, there were 50 plants with a total electrolysis capacity of approximately 50 MW in operation or planned. Then, further electrolysis capacity of the PtG projects announced by the end of 2019 reached almost 600 MW (Figure 2-2).[29] The PtG systems substantially increased in size and a PtG system with an electrolyzer of 100 MW is expected to operate in the future.

[25] IPHE. *op.cit*.
[26] Jensterle, M. et al. (2019). *op.cit.* p.5.
[27] *Ibid*. p.7
[28] Strategieplattform Power to Gas. https://www.powertogas.info/die-plattform/
[29] TÜV SÜD (January 28, 2020). “Power-to-Gas expansion on steep growth path” (https://www.tuvsud.com/en/press-and-media/2020/january/power-to-gas-expansion-on-steep-growth-path)

Fig. 2-2 Development of PtG plant capacity in Germany in 2019



Source: TÜV SÜD

Among the various PtG demonstration projects, the following part briefly illustrates some projects at large-scale and in the industry and residential sectors.

(1) Large-scale green hydrogen projects

ELEMENT EINS: The transmission system operator TenneT and the gas transmission operators Gasunie Deutschland and Thyssengas plan to build a 100 MW PtG pilot plant around the area of the TenneT substation Diele in Lower Saxony which collects and distributes offshore wind energy.[30] Using the existing gas infrastructure for the transport of hydrogen, the plant is expected to be gradually connected to the grid from 2022 and convert green electricity into gas which will facilitate decarbonizing the heat and industry sectors.

Hybridge: The transmission system operator Amprion and the gas transmission operator Open Grid Europe also plan a similar project called Hybridge.[31] With an investment of €150 million, a 100 MW PtG pilot plant will be installed near Amprion's substations in southern Emsland on the border between Lower Saxony and North Rhine-Westphalia. The pilot plant is to start conversion from electricity to hydrogen from 2023 and transport it via the existing gas network. The provision of hydrogen refilling stations in motor vehicles or trains and the hydrogen storage facilities are also included as a possibility in the further course of the project.

ReWest 100 (Reallabor Westküste 100): ReWest 100 plans to produce hydrogen from offshore wind energy on the west coast of Schleswig-Holstein, which then will be used to create climate-friendly fuels, fed into the gas network, and stored in a salt cavern.[32] In this five-year project, an electrolysis plant with a capacity of 30 MW will be installed initially to gain better understanding about the operation and maintenance, and grid serviceability of the plants, followed

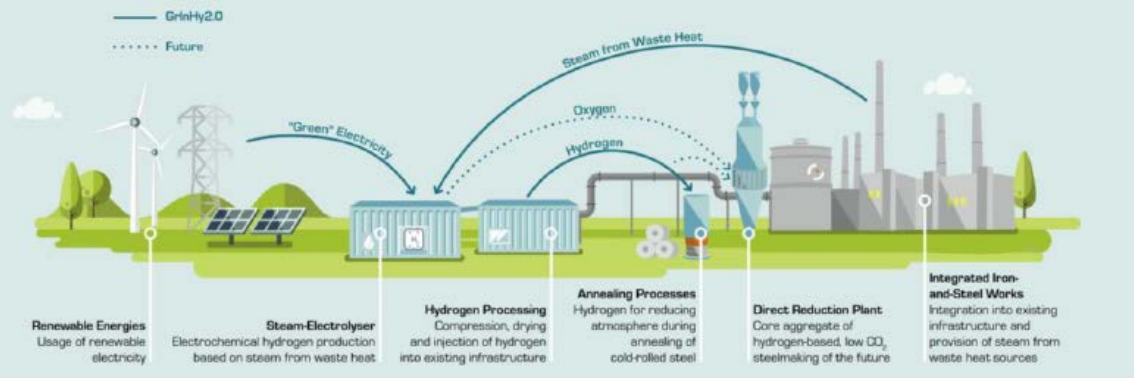
[30] TenneT (January 20, 2020). "Power-to-Gas-Projekt ELEMENT EINS fasst Standort Diele ins Auge" (https://www.tennet.eu/de/news/news/power-to-gas-projekt-element-eins-fasst-standort-diele-ins-auge/)
[31] Hybridge. https://www.hybridge.net/index-2.html
[32] Westküste 100. https://www.westkueste100.de/en/
Westküste 100 is a cross-industry partnership which consists of EDF Germany, Holcim Germany, OGE, Ørsted, Raffinerie Heide, Stadtwerke Heide, thyssenkrupp Industrial Solutions, Thüga, Heide Region Development Agency, and the Fachhochschule Westküste University of Applied Science.

by the next phase of scaling up a plant to 700 MW. The project also aims to examine whether oxygen produced through electrolysis along with hydrogen can be fed into the combustion process of a cement plant to reduce CO_2 emissions.[33] Furthermore, CO_2 produced in the cement plant can be used as a raw material with hydrogen in the refinery to produce synthetic fuels such as aviation fuels or chemical raw materials. Consequently, this process will help the cement and aviation industries to be decarbonized.

(2) Industry sector

GrInHy/ GrInHy2.0: Between March 2016 and February 2019, GrInHy (Green Industrial Hydrogen via steam electrolysis) was conducted to evaluate the energy efficiency and performance of reversible high-temperature electrolysis based on a solid oxide electrolysis cell (SOEC) with a capacity of 150 kW in the process of iron and steel works. As a result of the operation for approximately 10,000 hours, since a significant share of energy input was provided from waste heat as well as renewable energy in the steelworks, the high-temperature electrolysis achieved high efficiency of 84 $\%_{LHV}$ although stack testing was stopped after 8,300 hours due to contaminations and failures of the test bench.[34] A successor project, GrInHy2.0, started in January 2019 with a scaled up high-temperature electrolyzer of 720 kW to test and prove the technology (Figure 2-3).[35] By the end of 2022, this project will be in operation for at least 13,000 hours and produce 100 tons of high-purity (99.98%) green hydrogen at under €7/kg. Five partners - Salzgitter AG, Sunfire, Paul Wurth, Tenova, and CEA – work on the GrInHy2.0 project with a budget of €5.5 million.[36]

Fig. 2-3 Schematic of GrInHy2.0



Source: GrInHy2.0

[33] Oxyfuel combustion is a technology to capture CO_2.
[34] GrInHy2.0. https://www.green-industrial-hydrogen.com/
[35] Salzgitter AG and Sunfire GmbH (March 14, 2019). "GrInHy2.0 – Hydrogen for low-CO2 steelmaking." (https://www.green-industrial-hydrogen.com/fileadmin/user_upload/2019_March_GrInHy_2.0_press-release.pdf)
[36] GrInHy has eight partners from five different EU countries - Salzgitter Mannesmann Forschung GmbH, Salzgitter Flachstahl GmbH, Boeing Research and Technology Europe, Sunfire GmbH, VTT Technical Research Centre of Finland, EIFER - European Institute for Energy Research, Institute of Physics of Materials, Brno, and Politecnico di Torino.
Salzgitter AG has been proactive to reduce CO_2 emissions in steel production under the project SALCOS (Salzgitter Low CO_2 Steelmaking).

CCU P2C Salzbergen: This project tests a CCU process which captures CO_2 and uses it for different applications. CO_2 emitted by a local waste incineration plant in Salzbergen is captured in a prototype on an industrial scale (64,000 t-CO_2/year) and then CO_2 and green hydrogen are converted into synthetic fuels.[37]

(3) Residential sector

Exytron climate-friendly living/ Exytron Zero-Emission residential park: Exytron provides an environmentally friendly energy system that produces hydrogen from renewable energy and coverts it into synthetic methane which can be stored in the building and burned in a CHP or boiler to meet demand for electricity, heat, or cold as necessary.[38] The cyclical system in which CO_2 released from the CHP or boiler is used to produce methane lowers CO_2 emissions substantially. This PtG system is effective not only for new buildings (e.g., 37 residential units supplied with electricity and heat from the PtG system in Alzey) but also for renovation of old buildings (e.g., 70 units supplied electricity from a rooftop PV as well as heat and electricity from the PtG system of a renovated block of flats from 1974 in Augsburg). This decentralized PtG case demonstrated energy efficiency improvement and decarbonization of the buildings.

Conclusion

Germany's National Hydrogen Strategy is to accelerate the energy transition. That the Federal Government showed approaches for hydrogen deployment and clarified the support for technology innovation will stimulate private investment in the fields related to hydrogen with expectations for business opportunities. Taking hydrogen imports into consideration, the Federal Government will establish and strengthen a partnership with countries which envisage hydrogen exports. In fact, Germany and Morocco signed an agreement on the development of the green hydrogen production sector right after the National Hydrogen Strategy was announced.[39]

Germany's advantage is that hydrogen development can be accelerated across Europe as the momentum toward hydrogen uptake has been heightened in Europe as well as Germany. With the European Green Deal aiming for no net GHG emissions by 2050, the EU is committed to take effective measures which advance decarbonization. In Europe, there are countries in which renewable energy accounts for the majority of power generation such as Norway and Spain. Norway actually released the hydrogen strategy in June 2020, as well. It is highly possible that green hydrogen development will speed up once a regulatory framework is established and agreed among European countries with regard to hydrogen utilization such as fuel cells and use of existing gas networks.

Japan launched the *Basic Hydrogen Strategy* in 2017. While the basic policy directions

[37] BMWi (2019). "Gewinner des Ideenwettbewerbs „Reallabore der Energiewende" – Steckbriefe –" p.1 (https://www.bmwi.de/Redaktion/DE/Downloads/P-R/reallabore-der-energiewende-gewinner-ideenwettbewerb-steckbriefe.pdf?__blob=publicationFile&v=9)
[38] Exytron. https://exytron.online/en/the-principle-of-smart-energy-technology-zero-emission-technologys/
[39] Guessous, H. (June 10, 2020). "Morocco First to Partner with Germany to Develop Green Hydrogen Sector" *Morocco World News*

towards hydrogen society are common in the strategies of both Japan and Germany, there are some differences between the two countries. For instance, Japan's strategy explicitly presents the specific targets in hydrogen supply costs and applications. Japan will establish commercial-scale supply chains by 2030 to procure 300,000 tons of hydrogen annually and ensure that the hydrogen cost will be JPY30/Nm^3 (USD3.2/kg). Japan's strategy also includes hydrogen power generation as an application and aims to commercialize hydrogen power generation with the generation cost of JPY17/kWh (USD0.16/kWh) by around 2030. In the transport sector, Japan's strategy centers on fuel cell technology and sets a numerical target for FCVs, FC buses, and FC forklifts but does not touch on aviation fuels. In contrast, Germany intends to use electricity-based jet fuel which is produced from green hydrogen, given focuses on the use of synthetic fuels in the transport sector in general.

The Germany-Japan economic relationship has been strong. Friendly rivalry as well as collaboration may advance technology development and innovation of hydrogen further. The two countries have paid attention to green hydrogen in the bilateral cooperation so far. However, they have expanded the hydrogen schemes, indicating a new opportunity for both countries. Germany has accepted blue hydrogen although it is a transitional technology and imported only. Japan conducts demonstration projects to produce green hydrogen while seeking imports and utilization of blue hydrogen. The latest development is that the Fukushima Hydrogen Energy Research Field (FH2R) with a renewable energy-powered 10MW-class hydrogen production unit started operation in March 2020.[40] It is essential to reduce hydrogen production costs through technology development if a hydrogen society is expected. Both Germany and Japan will continuously improve hydrogen technology levels to gain competitive advantages, which will contribute to decarbonization globally.

[40] New Energy and Industrial Technology Development Organization (March 7, 2020). "The world's largest-class hydrogen production, Fukushima Hydrogen Energy Research Field (FH2R) now is completed at Namie town in Fukushima - This demonstration project will be operating to aim for low-cost Green hydrogen production technology -" (https://www.nedo.go.jp/english/news/AA5en_100422.html)