Development and Demonstration toward Hydrogen Energy Introduction Essential for Establishing a Decarbonized Society

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Introduction

Kawasaki is the only company in the world who holds in a single company all the core technologies to produce, transport, store, and utilize hydrogen, which covers the entirety of a hydrogen energy supply chain. The history of these core technologies originated with liquefied natural gas (LNG) technology, in which we have accumulated numerous achievements over the past half century.

The need for such technologies, unique to us as a general heavy industrial company is increasing and those technologies are rapidly gathering momentum as people expect to prove to be useful for the global environment and the future of humankind. Hydrogen is a clean energy that emits no CO_2 when used, and it has been recognized as being essential for achieving the goal of the Paris Agreement, that is, net zero CO_2 emissions by the end of this century. In response to this, many countries are incorporating the utilization and supply of hydrogen into their policies.

We have been conducting research and development on the establishment of a hydrogen energy supply chain since fiscal 2010, and finally, in fiscal 2020, our first-in-the-world demonstration project is entering the operation phase. In addition, in order to achieve commercial operation in the early 2030s, we are continuing the development of technologies and are in the process of establishing a business entity.

1 Changes in environment and society

In 2005 the Kyoto Protocol became effective with the aim of creating a low carbon society. In 2015 the Paris Agreement was adopted, and after that, 187 countries and regions submitted their own goals to realize a decarbonized society. However, global environmental change is occurring faster than such changes in social environment, and CO_2 reduction is no longer just an environment issue but an urgent social issue.

The countries that signed the Paris Agreement have set their target for CO_2 reduction, and among them, Norway, Sweden, France, the UK, and others have legislated net zero emissions by 2050. Japan's target is an 80% reduction by 2050, and net zero emissions as soon as possible after 2050. To achieve such targets just by saving energy is obviously impossible, so continued introduction of renewable energies is indispensable.

However, Japan is already the leading country in terms of renewable energy introduction density, but it has challenges to overcome such as location and cost reduction whenever it expands its renewable energy generation facilities. **Figure 1** shows renewable energy density, which is calculated by dividing renewable energy generation by habitable land, the remainder of subtracting forest land from the land area of the entire nation. Japan's density is higher than Germany's, one of the leading countries in renewable energy introduction. Japan is also among the countries with the highest energy consumption density, as shown in **Fig. 2**, and it would be very constrained if it were to introduce and expand enough renewable energies in its limited national land to cover such high demand.

Given this background, a new zero-emission, less-expensive energy that is abundantly available and that contributes to the realization of a decarbonized society, which at the same time satisfies the criteria for selecting future sources of energy as defined by what is known as energy security, economic efficiency, environment, and safety (3E+S), is being sought after. The result is that the idea of converting less-expensive, unused resources and renewable energies in other countries into hydrogen, and transporting the hydrogen to Japan to make use of it has drawn attention.

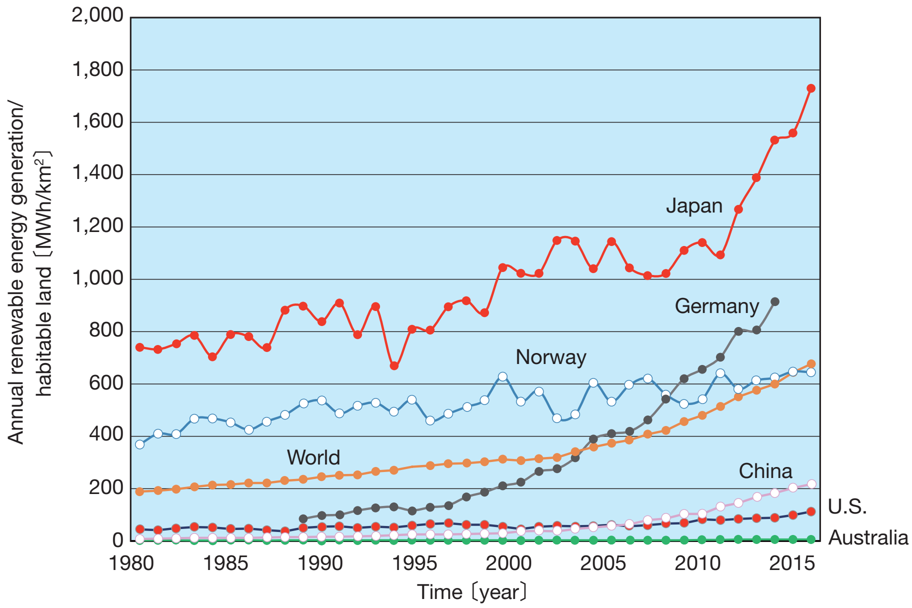


Fig. 1 Renewable energy density*

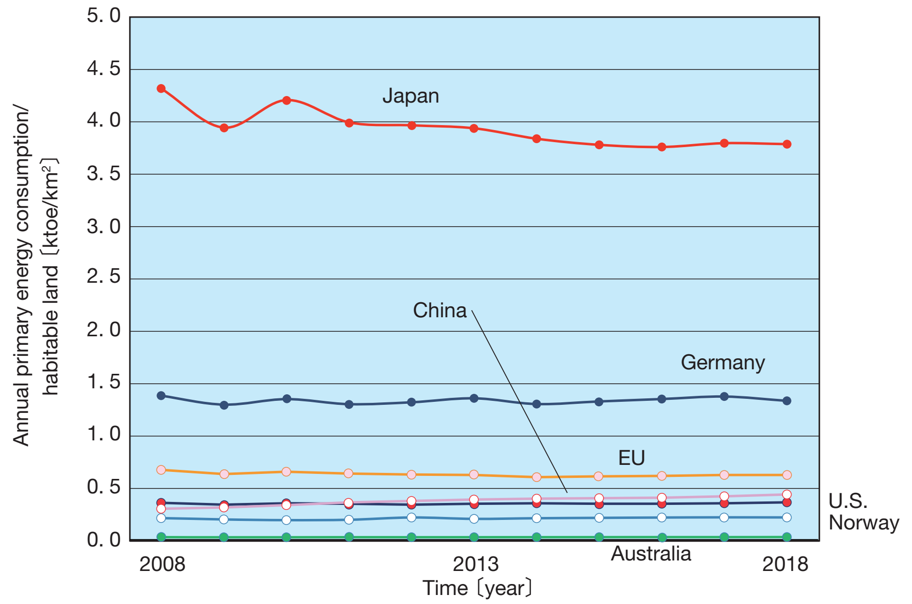


Fig. 2 Energy consumption density*

2 Japan's strategy on hydrogen

The Council for a Strategy for Hydrogen and Fuel Cells was established in December 2013 gathering experts from industry, government, and academia as part of an initiative by the Ministry of Economy, Trade and Industry. The council released the Strategic Roadmap for Hydrogen and Fuel Cells in June 2014. The roadmap was renewed in 2016 and 2019, and the latter clarifies the cost target for hydrogen and the performance target for key equipment and systems toward social implementation of hydrogen and fuel cells, and defines action plans to achieve these targets.

The Strategic Energy Plan, which is the basis of Japan's energy policy, starts covering hydrogen in its fourth edition released in April 2014. While hydrogen has been incorporated into the nation's policies in this way, in December 2017 the Basic Hydrogen Strategy was formulated and released through cross-ministerial cooperation. The strategy aims to commercialize hydrogen fueled power generation and a hydrogen energy supply chain early in the 2030s, and it presents a vision that the capacity of future hydrogen fueled power generation will reach 30 GW.

* Data source: Website of US Energy Information Administration, and BP Statistical Review of World Energy (2019)

While promoting hydrogen policies ahead of the rest of the world, Japan hosted Hydrogen Energy Ministerial Meetings in Tokyo in September 2018 and 2019 attended by related ministers from around the world.

3 Global movement toward hydrogen utilization

Japan has been a leader in the utilization of hydrogen energy in the world, but in recent years, every country, both in the West and the East, is aiming to utilize hydrogen. One reason for this is the Hydrogen Council. The council was established in January 2017 by 13 major companies of various industries from around the world such as energy and resources, plants, industrial gas, and transportation machinery, and its aim is to promote hydrogen utilization toward a decarbonized society. The council, of which Kawasaki is a founding member, is expanding its scale with 92 companies as of the end of July 2020, including new members from the industries of fuel cells, trading, and banks.

Hydrogen Scaling Up, a report issued by the Hydrogen Council in November 2017, defines the following seven roles that hydrogen will play in terms of CO_2 reduction:

①Enables the mass introduction of renewable energy and hydrogen fueled power generation

②Enables energy accommodation and transportation between sectors and between regions

③Increases the flexibility of energy systems as a buffer

④Enables low carbonization in transportation

⑤Enables low carbonization in energy for industrial use

⑥Enables low carbonization in heat and electricity in buildings

⑦Enables the supply of low-carbon materials for industrial applications

The important thing here is that hydrogen is superior to a secondary battery in storage amount and duration, transportation range, and cross-sectoral accommodation ability, and has a far larger number of players who can engage in various hydrogen businesses such as hydrogen supply and utilization. This means that hydrogen's unique features could become a strong driving force for energy transition and bring benefits to both energy systems and end use. This report estimates that the economic effect of hydrogen in 2050 will be 2.5 trillion dollars and jobs for 30 million people (which are equivalent to the current number of jobs in the automobile industry) will be created. The report also encourages countries to refer to Japan's Strategic Roadmap for Hydrogen and Fuel Cells and formulate a roadmap tailored to their own situations. As a result, the U.S., EU, Australia, New Zealand, France, Germany, the Netherlands, Norway, Saudi Arabia, UAE, China, South Korea, and more have released or are formulating their roadmap.

Considering such global movement, some predict that a hydrogen-based society will come earlier than the previous forecast.

4 Establishment of hydrogen energy supply chain

The biggest challenge in hydrogen energy introduction is said to be cost and safety. To reduce cost, obtaining a large volume from inexpensive raw materials is effective and actually required. Considering this, we focused on brown-coal, which is a largely unused resource with abundant reserves in Australia. This inexpensive resource, for which there are no transactions with other countries, is used solely for local power generation, and its cost is a tenth that of coal.

In our project, a large amount of affordable hydrogen is stably produced from brown-coal, and by-product CO_2 is separated and captured, and then stored underground at the site (CCS: CO_2 Capture and Storage). This will enable the establishment of large-scale hydrogen supply infrastructure. In the future, we will realize the transition to a sustainable energy-based society by switching to hydrogen derived from inexpensive, foreign renewable energy.

When transporting hydrogen to Japan, long-range mass transportation will be in the form of liquefied hydrogen. Liquefied hydrogen has already been used for industrial applications and as rocket fuel for over half a century, and is a non-toxic, non-odorous, and global warming potential-free energy carrier conforming with requirements for a sustainable society. We regard liquefied hydrogen superior in sustainability above two other options being studied as energy carriers: ammonia, which is a deleterious substance, and organic hydride, which consumes energy to extract hydrogen.

As for safety, the other challenge in the introduction of hydrogen energy, as can be seen from the fact that hydrogen has a long history of use in numerous applications such as H2 rockets, industrial applications, fuel cell vehicles, hydrogen stations, and residential fuel cell appliances, we can use it safely, similar to other fuels, through understanding hydrogen's properties and handling it properly. To ensure perfect safety, we will continue to build up good results for mass utilization throughout the project, and demonstrate that hydrogen can be used safely in our daily lives.

As the door to commercialization, we are establishing a Japan-Australia pilot supply chain seamlessly running from start to end, as shown in **Fig. 3**. In 2016, Kawasaki, Iwatani

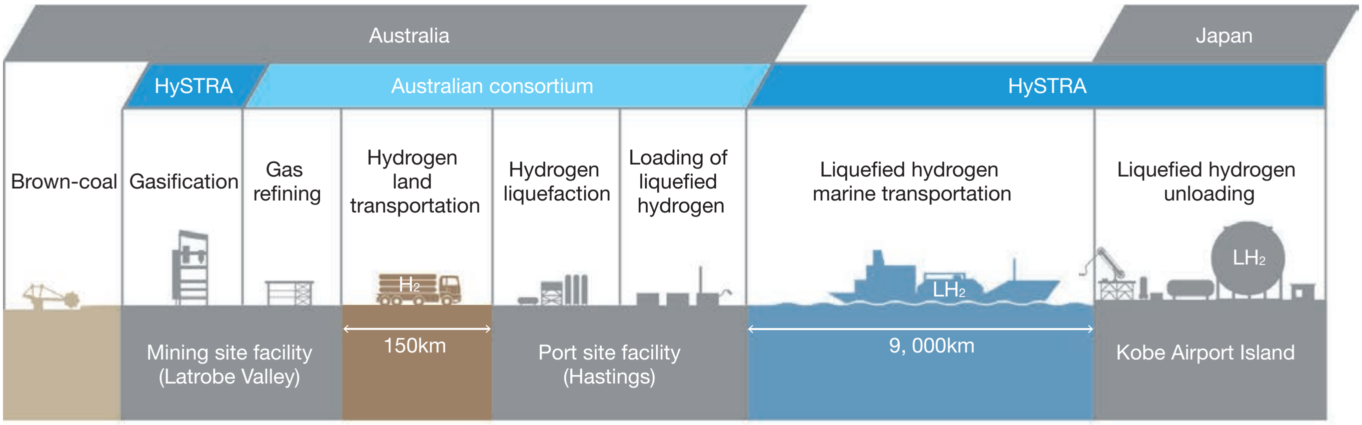


Fig. 3 Framework of Japan-Australia pilot supply chain

Corporation, Shell Japan Ltd., and Electric Power Development Co., Ltd. (J-POWER), came together to form the CO_2-free Hydrogen Energy Supply-chain Technology Research Association (HySTRA)—which was later joined by Marubeni Corporation, ENEOS Corporation, and Kawasaki Kisen Kaisha, Ltd.—and has been carrying out technology development to establish a hydrogen energy supply chain for the purpose of economical, stable procurement of a large amount of hydrogen with the support of the New Energy and Industrial Technology Development Organization (NEDO) (a grant project by NEDO called the Demonstration Project for Establishment of Mass Hydrogen Marine Transportation Supply Chain Derived from Unused Brown Coal). We are now commissioning a liquefied hydrogen carrier, a liquefied hydrogen unloading terminal in Kobe, and brown-coal gasification facilities in Australia.

Since Kawasaki, Iwatani, J-POWER, Marubeni, and AGL Loy Yang Pty Ltd formed a consortium in 2018, we have been constructing and commissioning gas refining facilities and a hydrogen liquefaction and loading terminal with a subsidy from the Australian government and the Victoria State government.

The construction of a liquefied hydrogen carrier and the facilities at each of the sites is well on track. In regard to our liquefied hydrogen carrier, a naming and launching ceremony was held in December 2019 (**Fig. 4**). The carrier was named SUISO FRONTIER and the ceremony was attended by 4,000 guests.

The governments of Japan and Australia cooperate in supporting the establishment of a hydrogen energy supply chain derived from brown-coal, and in a Japan-Australia summit meeting usually held at the end or beginning of the year, their cooperation on this project was announced in official documentation. The significant support for our consortium from the Australian federal and the Victoria State governments is part of that. In April 2018, a subsidy-awarding ceremony for this project was held in Latrobe Valley, where a brown-coal mining site is located. The construction of facilities is proceeding in Australia as well. These Japan-Australia pilot demonstrations have entered the operational phase that started in fiscal 2020.

Ahead of this, in fiscal 2018, as a grant project by NEDO, called the Smart Community Technology Development Project Utilizing Hydrogen Cogeneration Systems, under the coordination of Obayashi Corporation, in cooperation with Kobe City, the Kansai Electric Power Co., Inc., Iwatani Corporation, and others, Kawasaki successfully conducted a technological demonstration of gas turbine cogeneration, the key to hydrogen utilization, in a city area. We installed our 1 MW gas turbine (**Fig. 5**) on Kobe Port Island, and it successfully supplied heat and electricity to neighboring public facilities. This is the first time in the world that a hydrogen fueled gas turbine was operated in a city area.

As the proportion of renewable energy gets larger in the future, problems will be revealed, such as unstable power supply caused from fluctuating renewable energy sources and mismatches between electricity supply and demand. A way to solve this mismatch is power-to-gas technology, which is the idea of supplying surplus electricity generated from renewable energy to a water electrolysis, producing and storing hydrogen, and utilizing the stored hydrogen as energy.

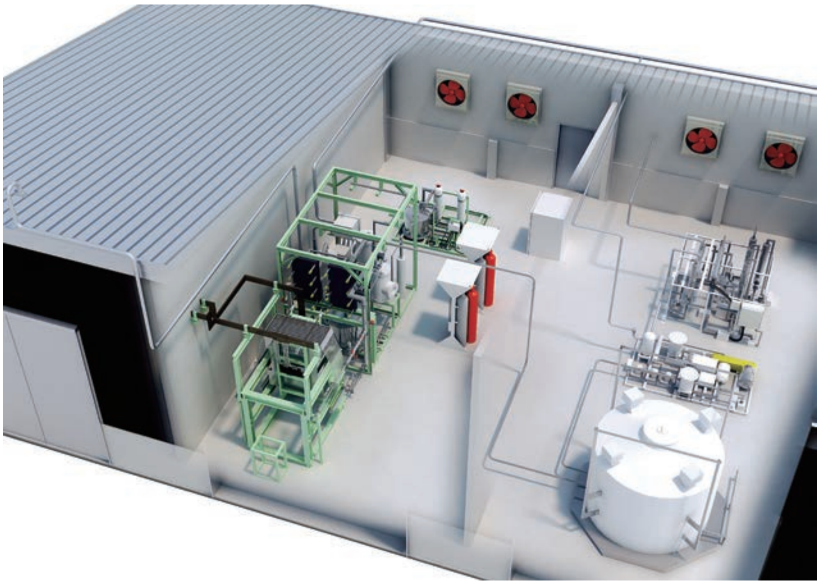
In 2018, under the coordination of Toyota Tsusho Corporation, Kawasaki conducted a power to gas demonstration commissioned by NEDO, called the Research and Development of Technologies for Stabilization, Storage and Use in Converting Unstable Electric Power Derived from Renewable Energies into Hydrogen in Hokkaido, in which we connected a water electrolysis system to a wind power generation facility in

Fig. 4 Launching ceremony of the liquefied hydrogen carrier SUISO FRONTIER

Fig. 5 Demonstration facility for hydrogen fueled gas turbine cogeneration (in Kobe City)

Tomamae, Hokkaido and successfully produced hydrogen. **Figure 6** shows the hydrogen production facilities. Such hydrogen derived from renewable energy is essential to establishing a sustainable energy-based society, and is needed to some extent even when considering the energy self-sufficiency rate. This technology will be important when hydrogen is produced using inexpensive renewable energies of other countries, which also offers hope that a large market will form.

(a) External appearance



(b) Equipment layout

Fig. 6 Wind-powered hydrogen production demonstration facility (Tomamae, Hokkaido, in 2018)

Conclusion

Kawasaki has been carrying out development projects for each phase in the realization of a hydrogen-based society, which includes the production, transport, storage, and utilization of hydrogen as actions based on the Sustainable Development Goals (SDGs). If we can utilize economical hydrogen derived from brown-coal to install infrastructure, and then switch to hydrogen derived from renewable energy, which is expected to have further cost reduction effects and a larger amount of production in the future, we will realize transition to a sustainable energy-based society.

By carrying out demonstrations toward future commercialization in a safe and steady manner, Kawasaki will facilitate hydrogen-related product development and commercialization to embody "KAWA-ru SAKI-e," or "Changing forward" in English, exploiting the synergy of Kawasaki Group technologies, and move forward to become the top hydrogen manufacturer.