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Japan's Hydrogen Society Ambition
2020 Status and Perspectives

Monica NAGASHIMA

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Center for Energy

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Executive Summary

Japan has been steadfastly promoting the development of its hydrogen (H_2) economy at all levels: political, diplomatic, economic and industrial. It is yet to be seen if this excitement can be turned into a credible, cost-effective and large scale deployment.

The strategy has a supply side, transport and end-use side which are all actively being pursued through pilot and large scale projects involving a number of Japanese companies and increased public funding. Japan's hydrogen energy ambition is an industrial endeavor aimed at fostering technological innovation. The domestic energy policy has so far left little room for clean technologies (other than nuclear), choosing to prioritize nuclear energy and fossil fuels instead in the long term. While the importance of decarbonized hydrogen production is communicated through the strategy, this must not become an afterthought, as decarbonization is the only property that makes hydrogen marketable. The strategy is also not prioritizing applications in some hard to abate sectors, such as air transport or heavy industries, and focuses rather on sectors where electrification (and decarbonization through renewables) could be more preferable.

Japan is a hydrogen frontrunner in terms of mobilizing R&D across various sectors and has successfully completed many first of a kind demonstrations. It remains to be seen whether hydrogen will be the preferred fuel for shipping, while there are high expectations for ammonia and organic carriers. Ambitious targets in power generation and fuel cell vehicles (FCVs) appear questionable though, meeting the thermal generation targets could require between 100 to 1,000 times higher volume of hydrogen than the demand of 800,000 fuel cell vehicles, which constitutes in itself an ambitious ten-year goal given that circa 3,700 FCVs have been sold in six years. The international hydrogen value chains that Japanese stakeholders are exploring in view of meeting the bulk of domestic demand are more interesting in combination with the development of clean hydrogen, notably via the use of carbon capture and storage (CCS) or low carbon electricity electrolysis. Overall, despite a high energy price environment in Japan, the competitive edge of hydrogen will prove challenging to materialize, especially in a low cost oil, gas and coal environment.

Japan still needs to decide what greenhouse gas (GHG) trajectory it will take in the coming two decades, and whether it wants to give priority to its economic short term competitiveness over longer term environmental and international benefits. Current policy dynamics in Japan give a smaller voice to the proponents of an environmentally friendly policy compared to the interests of the industrial sector, which has been sounding the alarm over higher energy prices in Japan and now more recently, over the consequences of the COVID-19 recession. As an example, discussions around a carbon price are nowhere close to consensus. An encouraging sign for clean technologies has been the recent government announcement on the phase out of inefficient coal and a statement by Minister of Economy, Trade and Industry (METI) in July. As a result, it appears that Japan will deepen deliberations on making "renewables the main power source". It remains to be seen to what extent this shift will be reflected in the 2021 revision of the Basic Energy Strategy, which will shape Japan's energy mix for the next decade and beyond. The current (2018) Strategy gives renewables a 22-24% share of the electricity mix compared to a greater 26% share of coal by 2030. Without a coordinated policy and business direction towards economy-wide decarbonization, especially in a context where even the more mature renewables struggle to gain a foothold, it is hard to see a business case for clean hydrogen and fuel cells in the near future.

At a time when the European Union and its Member countries are coming up with ambitious clean hydrogen strategies and sector coupling plans – with large state driven funding soon available, considerations on raising internal carbon prices and the development of a carbon border adjustment mechanism – Japan could reconsider its options. Failure to advance its decarbonization could ultimately lead to trade tensions with the European Union and constrain its industrial leadership ambitions globally.

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Introduction

It will take another year for Japan to see the hydrogen flame torches and fuel cell buses at the Tokyo Olympics. The latter intended to serve as a platform to showcase the country's leadership in hydrogen technology and its commitment to establish the world's first "Hydrogen Society". Hydrogen is promoted as one of the potential solutions to Japan's energy priorities, known as 3E+S: Energy Security, Economic Affordability, Environment and Safety. Fossil fuels currently contribute to over 87% of Japan's primary energy supply, which poses a challenge to meeting the national target of 80% reduction in GHG by 2050. Hydrogen could be the solution to reducing emissions.

Following the December 2017 Basic Hydrogen Strategy[1] document published by the METI, which set a comprehensive view and strategy and which was discussed in a precedent Ifri paper by the author,[2] Japan updated its Strategic Road Map for Hydrogen and Fuel Cells in 2019. It also released a Hydrogen research and development (R&D) strategy, and leveraged its position as the host of high profile global summits to foster international cooperation like the G20 and the Hydrogen Energy Ministerial Meeting.

Japan aims to pioneer a global supply network for hydrogen production, shipping and applications in various economic sectors. For Japan, the majority of hydrogen and other derivative fuels are expected to be imported from overseas. Carrier technologies (storage and distribution of hydrogen), fuel cells and electrolysers have been identified as key R&D priorities since 2014 and this position was reinforced in 2019. An indicator of success would be the adoption of hydrogen in thermal power generation on a commercial scale in the coming years. With about 132 gigawatts (GW) of thermal power installed, only a slight fraction could realistically run on hydrogen (government estimates 15-30 GW in the long term). Given the large volume of fuel required to meet the high demand which is anticipated in the future, the Japanese strategy includes both green and blue hydrogen in its long term plans and stresses the necessity of competitive cost.

1. *Basic Hydrogen Strategy,* Ministerial Council on Renewable Energy, Hydrogen and Related Issues, METI, Japan, December 26, 2017, available at: www.meti.go.jp.

2. Note: M. Nagashima, "Japan's Hydrogen Strategy and Its Economic and Geopolitical Implications", *Études de l'Ifri*, Ifri, October 2018, available at: www.ifri.org.

The METI allocated a budget of 80 billion yen ($748 million – dollars) to R&D and consumer subsidies for hydrogen technologies and clean mobility in FY 2020, up from 60 billion yen ($560 million) in FY 2019.[3]

Japan aims to reduce the cost of clean hydrogen fuel as well as related technologies along the supply chain by scaling up their production and dissemination. Areas of focus include: hydrogen production (including electrolysers); carrier technologies and international supply chains; the application in fuel cells, mobility and power generation. The industry sector so far, is not the priority.

While it is difficult to assess how the pandemic will affect Japan's efforts going forward, this note aims to take stock of the latest developments on the supply, transport & trade, CCS and demand sides of hydrogen.

3. Exchange rate $1.00 = 107 yen. Source: *2020: Overview of Resource and Energy-Related Estimates*, Ministry of Economy, Trade and Industry (METI), Japan, August 2019, available at: www.meti.go.jp (in Japanese).

Japan's Hydrogen Strategy: Supply Side

Hydrogen production must be competitive with LNG

The target cost of hydrogen (whether and when it is clean is unclear) for 2030 is around 30 yen (28 cents of $)/Nm3 (normal cubic meter) and in the longer term (year unspecified but alluded to 2050) around 20 yen (19 cents of $)/Nm3. The goal is to achieve price competitiveness with import LNG, the major fuel in Japanese power generation. Since 2011, Japan's import LNG costs have varied between 7-15 $/MBtu (Million British termal unit), which translates to a calorific equivalent of hydrogen at 9-20 yen (8-19 cents of $)/Nm3. On top of this, the roadmap assumes that carbon prices will be better reflected in the energy market, hence propping up the economics of hydrogen further.

The cost of clean hydrogen production from gasified brown coal (including CCS) is currently "several hundred yen/Nm3" (several $/Nm3), based on preliminary results from the Japanese-Australian demonstration project in the state of Victoria.[4] Production costs are expected to come down to 12 yen (11 cents of $)/Nm3-hydrogen by 2022, including carbon dioxide (CO_2) capture and separation which is being developed for the commercial stage. Construction of the gasification plant began in November 2019 by J-Power, as part of the HySTRA consortium, which is developing the liquefied hydrogen supply chain.

To achieve these cost targets, the government estimates that the market volume of hydrogen for energy applications must reach 300,000 tons (t)-hydrogen/year by 2030 in Japan. In 2020, it stands at about 200 t-hydrogen/year.

4. *Hydrogen and Fuel Cell Strategic Roadmap*, Hydrogen and Fuel Cell Strategy Council, METI, March 12, 2019, available at: www.meti.go.jp.

Electrolysis

Reduction in the capital costs as well as improvement in the energy efficiency of electrolysers are key to the dissemination of clean hydrogen and power-to-gas technologies.

Japan aims to achieve the world's lowest system cost at 50,000 yen ($467)/kW (kilowatt) by 2030, which would be lower than the current large scale alkaline electrolysers that offer systems at around 500-1,000 $/kW. It remains to be seen whether China is effectively already capable of offering costs at around 200 $/kW. The energy efficiency of hydrogen production from electrolysis is planned to be increased from 5 kWh/Nm3 at the present to 4.3 kWh/Nm3 by 2030.[5] Durability and longevity, notably in PEM electrolysers also need to be improved. In Power-to-Gas systems where electrolysers are used for backup storage, power fluctuations and sudden surges in load can lead to their fast degradation.

To address these challenges, the 2019 Strategy outlines steps for the development of alkaline electrolysers, proton exchange membrane (PEM), solid oxide electrolysis cells (SOEC) and anion exchange membrane (AEM) technologies.

In March 2020, the world's largest 10 MW alkaline electrolyser powered by 20 MW of solar power began operating in Namie town, Fukushima prefecture. The electrolyser was developed by Asahi Kasei and is a single stack unit which can produce up to 1,200 Nm3-hydrogen per hour (or maximum capacity of 900 t-hydrogen per year). It was commissioned by "Fukushima Hydrogen Energy Research Field (FhydrogenR)" a project by the Japanese public R&D institute NEDO, Toshiba, Tohoku Electric Power Co, and Iwatani corporation.[6] The group will study the effects of fluctuating power on hydrogen production and storage, and aims to optimize the power supply and demand on the grid.

As for PEM systems, in 2019 Hitachi Zosen brought to the market Japan's largest PEM electrolyser with hydrogen production capacity of 200 Nm3/h for use with megawatt-scale wind and solar stations.[7]

Japan and New Zealand signed a Memorandum of Cooperation in the field of renewable hydrogen and supply chains in October 2018.

5. 5th Basic Energy Plan, as cited p. 12 of March 2019 *Roadmap*.
6. "The world's largest-class hydrogen production, Fukushima Hydrogen Energy Research Field (FH2R) now is completed at Namie town in Fukushima", Press Release, Toshiba, March 7, 2020, available at: www.toshiba-energy.com.
7. "Hitachi Zosen Develops Japan's Largest Megawatt-scale Solid Polymer Hydrogen Generation System", News Release, Hitachi Zosen Corporation, June 13, 2018, available at: www.hitachizosen.co.jp.

In December 2018, Obayashi Corporation and Tuaropaki Trust of New Zealand signed an agreement on joint R&D and began the construction of the 1.5 MW hydrogen plant that will produce 100 t-hydrogen using electricity from Tuaropaki's geothermal power plant. The production plant will be completed in 2020.[8]

International supply chains – shipping and distribution of hydrogen

The capacity for domestic hydrogen production being limited, clean hydrogen produced overseas and transported to Japan is expected to be more competitive. Japan has notably struggled to lower the cost of renewable electricity to the extent seen in other parts of the world. In 2019 the average bidding price for large scale solar power was 12.91 yen (12.1 cents of $)/kWh – two times higher than in Europe, while onshore wind was 19 yen (17.8 cents of $)/kWh – three times higher than in Europe.[9] Japan has yet to decide what type of hydrogen imports it will favor given technological and economic constraints, with all bets still out on the subject.

Japanese companies are developing a number of transport and storage technologies including: liquefaction, organic hydrides such as methylcyclohexane (MCH), and ammonia. Imported ammonia was identified as the least expensive energy carrier for Japan in 2030 by the IEA,[10] but views on the future competitiveness of each option vary among the stakeholders.[11] Owing to the difference in physical properties and specificities of application, several solutions could ultimately find a market at this stage, whilst further research is pursued in parallel.

Liquid Hydrogen (Lhydrogen)

The world's first liquefied hydrogen carrier ship "Suiso Frontier" was unveiled by Kawasaki Heavy Industries in December 2019. Once the construction of the ship is completed by late 2020, it will be used to test the transportation of liquefied hydrogen (cooled at -253°C) from Australia to Japan. This a milestone for HySTRA, a consortium of Kawasaki, Iwatani, Shell, J-Power, and NEDO which have been developing various technologies

8. "Joint Development Agreement Signed with Tuaropaki Trust, Will Build Hydrogen Production Plant", News, Obayashi, January 28, 2019, available at: www.obayashi.co.jp.
9. "Procurement Price and Other Matters for FY2020", METI, February 4, 2020, available at: www.meti.go.jp (in Japanese).
10. *The Future of Hydrogen: Seizing Today's Opportunities*, IEA, June 2019, available at: www.iea.org.
11. M. Yuji *et al.*, "Economic Analysis on International Hydrogen Energy Career Supply Chains", *Journal of Japan Society of Energy and Resources,* Vol. 38, No. 3, April 2017.

for the Japan-Australia hydrogen supply chain since 2016. In addition to the liquefaction carrier, the consortium is also building a brown coal gasification facility in Victoria, Australia as well as a hydrogen regasification terminal in Hyogo, Japan, with large state funding. Total project costs are in the $500 millions range.[12]

The Australian government is financing other segments of the supply chain handled by the consortium of Japanese Kawasaki, Iwatani, J-Power, Marubeni, and Australian AGL Loy Yang. This group will develop a gas refining facility, hydrogen liquefaction plant, and loading terminals, etc. Japan's updated 2019 hydrogen strategy aims to improve the efficiency of the liquefaction process from 13.6 kWh/kg to 6 kWh/kg.[13]

The high moisture content of brown coal renders it a low grade commodity, unusable in the export markets whilst resulting in an extremely polluting production of hydrogen[14]. While the long term commercialization of the supply chain is contingent on the capture and storage of CO_2 in Australia,[15] CCS will not be part of this pilot project.

Organic Hydrides – Methylcyclohexane

Chiyoda Corporation developed a hydrogenation method which combines toluene with hydrogen to form MCH. MCH is an organic hydride that allows the transportation and storage of hydrogen at standard temperature and pressure, but the challenge lies in reducing the energy and cost requirements for reconversion into hydrogen. Chiyoda, in partnership with Mitsubishi Corporation, Nippon Yusen (NYK), and Mitsui & Co. launched the demonstration of shipping of MCH from Brunei to Japan. In May 2020, the hydrogen extracted from MCH was successfully used as fuel in gas power generation and in June the toluene was shipped back to Brunei for re-hydrogenation, thus successfully completing the full cycle.[16]

The National Institute of Advanced Industrial Science and Technology (AIST) is also developing an MCH carrier and it has announced the

12. "Local Jobs and a New Energy Industry for the LaTrobe Valley", Department of Industry, Science, Energy and Resources, Australian Government, April 12, 2018, available at: www.minister.industry.gov.au.

13. "The Strategic Road Map for Hydrogen and Fuel Cells. Industry-Academia-Government Action Plan to Realize 'Hydrogen Society'", METI, 2019, available at: www.meti.go.jp.

14. Hydrogen production from coal gasification results in about twice the carbon emissions of hydrogen production from natural gas reforming. CCS can reduce about 90% of carbon emissions at production. Source: IEA Hydrogen 2019 Report, *op. cit.*

15. "The CarbonNet Project", Earth Resources, March 19, 2020, available at: https://earthresources.vic.gov.au.

16. "World's First Global Hydrogen Supply Chain Demonstration Project Starts in Earnest", News Release, NYK, June 19, 2020, available at: www.nyk.com.

completion of the domestic renewable supply chain demonstration in Fukushima in March 2020.[17] The research focused on optimizing the production of MCH using hydrogen derived from variable renewables. Hitachi supplied the technology to extract hydrogen from MCH for use in thermal power generation.

Ammonia

Ammonia is a widely traded commodity with a mature production, shipping and distribution network which has been used in the fertilizer and chemical industries for many decades. The Strategic Innovation Promotion Program run by the Cabinet Office of the Japanese Government (2014-2018) found that ammonia has potential as an energy carrier for hydrogen and as a direct fuel source for power generation as well as industrial applications. Importantly, the Natural Resources and Fuel Department of METI in its 2020 outlook on traditional fossil fuel energy and resource procurement, has recognized ammonia as a potential clean fuel that can address climate change.[18]

At a high-level bilateral symposium between Japan and Saudi Arabia in July 2019, the Institute of Energy Economics Japan (IEEJ) and Saudi Aramco signed a memorandum of understanding (MoU) for a pre-feasibility study of carbon-free ammonia production in the Kingdom of Saudi Arabia.

A Japanese-Australian consortium comprised of IHI, JERA, Marubeni and Woodside Energy announced joint participation in a feasibility study on ammonia co-fired thermal power overseen by NEDO's Clean Coal Group.[19] The project aims to develop ammonia combustion technology that does not emit CO_2, including pulverized coal burners and vaporizers, and to identify challenges in cost reduction along the supply chain.

Japanese shipping company NYK is also exploring opportunities to use ammonia as a marine fuel.[20]

17. T. Tsujimura and H. Kojima, "Demonstration of a Hydrogen Supply Chain and a Hydrogen Co-firing Engine Generator System", AIST, April 9, 2020, available at: www.aist.go.jp.
18. "New International Resource Strategy Formulated", METI, March 30, 2020, available at: www.meti.go.jp.
19.Project period March 23, 2020 to February 28, 2021. www.nedo.go.jp; "Feasibility Study under NEDO Program on Ammonia Co-firing in Thermal Power Generation Facility", Press release, IHI, March 27, 2020, available at: www.ihi.co.jp.
20. "NYK Examines Concept of Using Ammonia as Marine Fuel", News release, NYK, January 30, 2020, available at: www.nyk.com.

Carbon Capture and Storage and Carbon Recycling – Carbon Price?

Both clean hydrogen produced from renewable electricity and from fossil fuels with CCS are part of Japan's long-term plans. Taking the current carbon intensity of hydrogen production from natural gas as a benchmark, Japan aims to reduce production emissions by 60% by 2030 and in the long term, achieve net zero CO_2 emissions across the entire hydrogen production to final use cycle.[21]

Therefore, technologies that address carbon emissions are a key aspect of the hydrogen strategy. In June 2019, under the Japanese presidency of the G20 summit, both hydrogen and the concept of Carbon Recycling were incorporated into the communiqué and action plan of the G20 Energy Ministers. Later in September, METI hosted a high-level Ministerial summit for Hydrogen, Carbon Recycling and LNG in the same week – emphasizing its support for cross-cutting cooperation between these three sectors.

Large scale demonstrations and cost reduction efforts will be pursued towards the commercialization of CCS. In the case of Australia's coal gasification project, the commercial potential of CCS is to be verified by 2025. R&D is focused on capture and separation technologies. Earlier Hydrogen Strategies had set the 2020 target cost for capture at 2,000 yen ($18.7)/t-$CO_2$. Japan will also double down on its efforts and participation in the harmonization of international CCS standards.

The challenge posed by conventional CCS systems is that the separation and removal of CO_2 results in additional capital costs and increased parasitic power,[22] while the potential for storage over many years is constrained by geographic location and weak international legal standards for liability.

There has been a recent push by the government and certain industries for Carbon Recycling: CO_2 could serve as a source of carbon atoms that could be incorporated into cement, synthetic fuels, plastics and polymers, which could turn CO_2 into a commodity. However the economic benefits of this concept as well the practical contribution to the rapid decarbonization of global energy systems is questionable.

The importance of reducing the carbon footprint of hydrogen is clearly acknowledged and various incentives are being explored, but they are yet to be implemented. In 2017, the METI CO_2 Free Hydrogen Working Group

21. *Hydrogen and Fuel Cell Strategy Roadmap. An Action Plan for Achieving a Hydrogen Society*, METI, March 12, 2019, p. 8, available at: www.meti.go.jp (in Japanese).

22. In power plants, conventional carbon capture and separation can increase the cost of electricity by 50% to 70%.

recommended a number of regulatory mechanisms to promote the trade and use of clean hydrogen.[23] This included the green electricity certificate (*green denryoku shosho*) and the J-Credit mechanism, currently used for procuring renewable credits and carbon offsets. The Working Group also recommended extending the laws requiring power generators to reduce their emissions intensity to include clean hydrogen. In the same year the Ministry of Environment formulated guidelines for calculating the carbon footprint of hydrogen supply chains.[24] Although the Japanese Hydrogen Strategy acknowledges that pricing reflective of "environmental value" will help hydrogen become competitive, the METI and the Keidanren (a prominent business federation)[25] appear to be opposed to domestic carbon pricing for fear it would undermine Japanese industrial competitiveness. Instead they show support for innovation as a means to address climate change, arguing that once the costs are brought down sufficiently (through R&D and pilot projects) then companies can switch over to the clean technologies.

23. *CO_2 Free Hydrogen Working Group – Report*, METI, available at: www.meti.go.jp (in Japanese).
24. *LCA Guidelines on the Greenhouse Gas Reduction Effectiveness of Renewable Energy and Hydrogen Energy*, Ministry of the Environment, Japan, available at: www.env.go.jp (in Japanese).
25. *For Carbon Pricing. Opposing Views*, Keidanren, October 13, 2017, available at: www.keidanren.or.jp (in Japanese).

Demand Side Developments

Fuel Cells Applications

ENE-FARM

ENE-FARM is a residential fuel cell system that generates electricity and heat using hydrogen extracted from natural gas or propane gas. While the gas reforming process at every home emits unavoidable CO_2 and NOx (nitrogen oxides) emissions, at the systemic level ENE-FARM is promoted for a lower environmental footprint compared to traditional utility powered homes as a result of higher output efficiency and avoidance of transmission. Over the years, developers have also focused on reducing the unit cost and physical dimensions, as well as extending the product life span (currently at around 20 years).

Since entering the market in 2009, over 300,000 units have been installed in Japan as of November 2019.[26] The roadmap targeted 1.4 million units by 2020 and 5.3 million units by 2030 (equivalent to 25% of Japanese households). Safety so far has not been an issue. The 2020 cost target for Polymer Electrolyte Fuel Cell (PEFC) was 800,000 yen ($7,500) and for Solid Oxide Fuel Cells (SOFC) 1 million yen ($9,300), with the aim to reduce the cost recovery period to 7-8 years. PEFC systems are no longer eligible for base subsidies and it is likely to be the case for SOFC systems soon as well (roadmap targets phasing out subsidies around this year).[27]

Industrial Stationary Fuel Cells

For commercial and industrial fuel cell systems, the government aims to achieve the system cost of 300,000 - 500,000 yen/kW and power generation cost 17 – 25 yen/kWh by 2025, depending on the pressure levels of the system. There is also a target for improving power generation efficiency and extending the life cycle.

26. "Cumulative Sales of ENEFARM Household Fuel Cells Exceed 300,000 Units", Enepharm Partners, November 21, 2019, available at: www.gas.or.jp (in Japanese).
27. Scheme changes from last year and key points for 2020, Fuel Cell Association, available at: www.fca-enefarm.org (in Japanaese).

In March 2020, Tokyo Gas and Miura Kogyo began the testing demonstration of jointly developed industrial Solid Oxide Fuel Cell (SOFC) system 5kW in scale with 65% generation efficiency.

MHPS developed a distributed hybrid system with SOFC and a micro gas turbine (MGT) under the brand name MEGAMIE. MEGAMIE achieves high efficiency by integrating ceramic SOFC stacks that reach 900℃ and through this exhaust hear operate the MGT.[28] Currently the system is being tested in university campuses, factories and commercial buildings, where there is demand for both electricity and heat. The MEGAMIE extracts methane from LNG or biogas (from breweries even)[29] which is then combined with recirculated water vapor from the exhaust to create hydrogen and carbon monoxide. The SOFC generates electricity through a chemical reaction of the carbon monoxide, hydrogen and oxygen, offering 47% system CO_2 reductions compared to conventional power and heat supply.[30]

It is worth noting that hydrogen is not supplied to the current residential and industrial fuel cells systems, but they rather use natural gas feedstock which becomes internally reformed into hydrogen. The conventional fuel requirements of the stationary fuel cells allow them to be used with the current pipeline infrastructure and easier to deploy compared to hydrogen or ammonia thermal combustion plants. And while the localization of natural gas reforming, especially in the context of electricity transmission, offers greater efficiency at the systemic level, the decentralized emissions are more challenging to abate.

Transport

Hosting the international Hydrogen Ministerial Meeting in 2019, METI released the chair's summary titled "Global Action Agenda" with the global "Ten, Ten, Ten" target: ten thousand hydrogen refueling stations and ten million fuel cell systems in ten years, with mobility infrastructure development and market expansion, highlighting the support among Japanese and other world economies for hydrogen in mobility.[31]

28. "MHPS Receives the Chairman's Award at the Cogeneration Awards 2019 for MEGAMIE", Press Release, Mitsubishi Power, No. 188, February 10, 2018, available at: www.mhps.com.
29. "Demonstration Project for Fuel Cell Power Using Biogas from Brewery Wastewater", Press Release, Mitsubishi Power, August 28, 2020, available at: https://power.mhi.com.
30. *Hydrogen – Powering a Net Zero Future. The Technologies to Get Us There*, Mitsubishi Heavy Industries, available at: https://oilandgas.mhi.com.
31. "METI Hosts Three Conferences: Second Hydrogen Energy Ministerial Meeting, First International Conference on Carbon Recycling and LNG Producer-Consumer Conference 2019", News Release, METI, September 27, 2019, available at: www.meti.go.jp.

Fuel Cell Vehicles (FCV)

Japanese automakers Toyota and Honda are frontrunners in the global fuel cell vehicle (FCVs) development. So far, the domestic reception of FCVs has been lukewarm, with only around 3,700 passenger units (3,573 Toyota Mirai[32] and the rest Honda Clarity FC) sold in Japan since the first FCV was launched in 2014. Several hurdles have to be addressed in order to meet the official dissemination target of 200,000 FCVs by 2025, and 800,000 FCVs by 2030 – including targets on reduction in vehicle cost and expansion of refueling stations.

The retail price of Toyota Mirai begins at 7.4 million yen ($69,000), which can be lowered with national and prefectural subsidies of up to 3.4 million yen ($32,000) for private consumers. The updated Hydrogen Strategy aims to bring down the cost of FCV by 1.1 million yen ($10,000) in five years, which is very ambitious. This includes slashing the cost of fuel cell stacks and hydrogen tanks to roughly one fourth by 2025, and further reduce to one fifth by 2030.[33]

Toyota and Honda are facing competition from Korea's Hyundai, which launched the NEXO fuel cell vehicle at the end of 2018. In its first year the NEXO sold 4,987 units (4,194 units in South Korea and 793 abroad) overtaking the Mirai which sold 2,494 units in 2019. Cumulatively Toyota Mirai has sold 10,682 units worldwide[34] and the company is expanding its production line to meet its annual global sales target of 30,000 units which includes 10,000 units domestically after 2020.[35]

In August 2020, Toyota registered a new joint venture in Beijing with Chinese auto companies to research and develop fuel cell systems.[36] The Chinese partners are FAW Group, Dongfeng Motor, Beijing Automotive, GAC and Beijing SinoHytec. Toyota will hold 65% majority stake in the venture, United Fuel Cell System R&D. In addition to tapping the fast-growing Chinese market, Toyota hopes to leverage the R&D capabilities of the influential automakers in order to strengthen its own global position in the fuel cell mobility sector.

32. "Sales, Production, and Export Results", Toyota, available at: https://global.toyota.
33. Target cost reduction for 2025 of fuel cell stacks from 20,000 yen/kW down to 4,000 yen/kW, and storage tanks from 700,000 yen to 100,000~200,000 yen by 2030.
34. "Sales, Production, and Export Results", Toyota, *op. cit.*
35. "Toyota moves to expand mass-production of fuel cell stacks and hydrogen tanks towards ten-fold increase post-2020", News Release, Toyota, May 24, 2018, available at: https://global.toyota.
36. Toyota-backed R&D JV for commercial fuel cell system founded in Beijing", Gasgoo, August 23, 2020, available at: http://autonews.gasgoo.com.

Hydrogen Refueling Stations

As of May 2020, 116 refueling stations are operational in Japan, or 130 locations if we include multiple sites serviced by mobile stations.[37] The initial rollout is focused on the four largest cities and key transit areas. Around 320 stations are expected to be operational in 2025, and 900 in 2030. Financial support for the development and operation of hydrogen stations is available through Japan Hydrogen Mobility (JHyM), a consortium of private companies, financial institutions and the government created to support the refueling business until 2027, roughly the time by which the refueling business will not require subsidies. By the end of the decade, the retail price of hydrogen is also set to be reduced by half from a current 1,000 yen ($9.35) per kg.[38]

Several ministries are passing regulatory reforms on hydrogen refueling stations to accelerate their development. Reforms include: an easing of requirements for expensive materials and components, shortening the distance requirements between facilities, lifting limits on hydrogen storage volumes, and changing other operating procedures in order to lower the costs.[39] Prescriptive regulations have contributed to the notoriously high cost of hydrogen stations in Japan, which can be two times higher than in other parts of the world. Japan has set out to reduce the CAPEX from 350 million yen to 200 million yen ($3.27 million to $1.87 million), and annual OPEX from 34 million yen down to 15 million yen ($318,000 to $140,000) by 2025.[40]

Self-servicing for passenger vehicles was legalized under new guidelines issued in 2018. These changes were introduced as part of measures aimed to roll back labor requirements, which account for roughly a third of the operating expenses[41]. Recently the government began accepting applications for operating licenses of unmanned refueling stations. The first one is expected to be opened by Air Liquide in Kawasaki in October 2020. Unmanned stations must meet specific conditions, including remote monitoring and ensuring that technicians can rush to the site rapidly in case of an emergency. The facilities must be equipped with dispensers that detect and stop automatically in the case of a hydrogen leak whilst follow protocols

37. "20 new HRS installed in fiscal 2020", News Release, Japan Hydrogen Mobility, May 28, 2020, available at: www.jhym.co.jp. About 20 stations have been approved for construction since October 2019. 23 stations were approved in 2019, 13 in 2018: "2 New HRS Installation Added in Fiscal 2019", News Release, Japan Hydrogen Mobility, November 1st, 2019, available at: www.jhym.co.jp.
38. *Progress Towards Achieving the Hydrogen and Fuel Cell Strategic Roadmap*, Hydrogen & Fuel Cell Strategy Office, METI, June 25, 2019, available at: www.meti.go.jp (in Japanese).
39. *Review of hydrogen Station Regulations*, High Pressure Gas Safety Office, METI, May 17, 2019, available at: www.meti.go.jp.
40. Stationary offsite model with supply capacity if 300 Nm3. *Hydrogen and Fuel Cell Strategic Roadmap,* March 2019, *op. cit.*
41. *Hydrogen and Fuel Cell Strategic Roadmap,* March 2019, *op. cit.*

on hydrogen storage and cyber security. Air Liquide anticipates that the process carried out at the Kawasaki station can be extended to others in Kobe and Aichi prefecture to turn them into unmanned stations in the future.

The strategy also includes R&D targets to improve the durability and cost of key components and equipment. Ultimately hydrogen stations are to be made more accessible and convenient for users by placing them next to convenience stores for example, and offering longer working hours.

Other Mobility Developments

Around 20 FC buses have been introduced so far. The target is to reach 100 buses by around 2020 and 1,200 buses by the year 2030. As for fuel cell forklifts, 160 units have been sold with the target for 2020 being 500 forklifts, and the 2030 target 10,000 forklifts. Seeing the potential for widespread application in the future, convenience store operators began demonstrations of fuel cell trucks. R&D and testing is also underway for fuel cell use in garbage trucks, tow trucks, and rail.

The shipping industry is also looking to hydrogen and ammonia as a way to meet the IMO global standards on greenhouse gas emissions. The Ministry of Land, Infrastructure, Transport and Tourism (MLIT) published the Roadmap to Zero Emissions in International Shipping in March 2020, in which hydrogen and ammonia are considered among the four potential options for the complete decarbonization of the shipping industry. The initial commercial launch of each prototype is expected between 2028-2030.

Power Generation

Japan's Basic Hydrogen Strategy aims for the commercialization of thermal power using hydrogen by 2030. This is contingent on the development of combustion technology and the availability of hydrogen fuel.

For hydrogen to be adopted by utilities which are obligated to provide reliable energy to end users, the fuel has to be available consistently, at low cost, and in sufficiently large volumes. The quantities involved in the future are likely much larger than those consumed in mobility: 1 GW of baseload power consumes 400,000 t-hydrogen/year (in whatever form), while the 800,000 FCVs expected by 2030 will consume ~100,000 t-hydrogen/year. There are 132 GW of fossil-fueled generation capacity in Japan. Replacing only 1/10 will require 50 million tons per year (Mtpy) H_2, which is 500 times more than the targeted FCVs.

The government estimates that a 15-30 GW of hydrogen generation capacity is the scale needed to achieve the necessary cost reductions to become competitive with LNG. Japan consumed around 50 million tons of LNG in 2018 in power generation, representing 35% of power supply that year. The government is also examining ways to use regulatory tools to promote hydrogen similar to the requirements on renewables shares or energy efficiency standards.[42]

The first demonstration of electricity and heat supply to an urban area using 100% hydrogen was achieved using a 1 MW turbine developed by Kawasaki Heavy Industries in 2018.[43] Pure hydrogen generation is more challenging for larger turbines. Mitsubishi Hitachi Power Systems (MHPS) successfully tested a 700 MW turbine that uses a mix of natural gas with 30% hydrogen. And in March 2020, MHPS was awarded a supply contract for two turbines to a U.S. coal power plant which will be refurbished to use natural gas and hydrogen. Commercial operations at the plant will start in 2025 using a mix of 30% clean hydrogen and 70% natural gas, following which the hydrogen concentration will be gradually raised to 100% by 2045.[44] Turbine developers also continue to focus on bringing down the concentration of NOx emitted during combustion.

The National Institute of Advanced Industrial Science and Technology (AIST) successfully completed the demonstration of renewable MCH supply chain for hydrogen co-fired power generation in March 2020.[45] AIST achieved the operational testing of 40-60% hydrogen blend with diesel thermal power generation for 1000 hours. For a brief duration at 300 kW capacity, the research was able to confirm generation with 80% hydrogen blend and 80% decrease in diesel fuel.

In March 2020, three Japanese companies JERA, IHI Corporation, and Marubeni in partnership with Australian Woodside signed an agreement with NEDO to participate in a feasibility study on the co-firing of ammonia in commercial thermal power plants.[46] The Basic Hydrogen Strategy states that "Japan aims to mix ammonia with coal at coal power plants by around 2020 and use ammonia for gas turbines by around 2030".

42. *12th CO_2 Free Hydrogen WG*, Hydrogen & Fuel Cell Strategy Office , METI, March 29, 2018, available at: www.meti.go.jp.
43. "World's First Heat and Electricity Supplied in an Urban Area Using 100% Hydrogen", New Energy and Industrial Technology Development Organization (NEDO), April 28, 2018, available at: www.nedo.go.jp.
44. "Intermountain Power Agency Orders MHPS JAC Gas Turbine Technology for Renewable-Hydrogen Energy Hub", News Release, Mitsubishi Power, March 10, 2020, available at: https://amer.mhps.com.
45. T. Tsujimura, and H. Kojima, "Demonstration of a Hydrogen Supply Chain and a Hydrogen Co-firing Engine Generator System", Press Release, AIST, April 9, 2020, available at: www.aist.go.jp.
46. *Feasibility Study under NEDO Program on Ammonia Co-firing in Thermal Power Generation Facility*, Marubeni, March 27, 2020, available at: www.marubeni.com.

Conclusion

Japan currently boasts a leading R&D portfolio of hydrogen and fuel cell related technologies. In order to ensure that these efforts progress towards commercialization, the government and stakeholders must focus on creating a business case for hydrogen. Japan still needs to resolve the broader debate on an effective path for its energy transition. Deliberations on the Basic Energy Strategy, which is set to be revised in 2021 and which will shape Japan's energy mix for the next decade and beyond, will start soon. The current (2018) Strategy gives renewables a 22-24% share of the electricity mix and a greater 26% share to coal by 2030. Without a coordinated policy and business direction towards economy-wide decarbonisation – in a context where even the more mature renewables struggle to gain a foothold – it is unclear how the market share of clean hydrogen and fuel cells will grow.

As it stands, hydrogen is not a clear solution to the national 3E+S concerns. Hydrogen will be predominantly imported from overseas and therefore strategic concerns over Japan's historical dependence on foreign resources and maritime routes are not alleviated. Hydrogen will remain costly for decades. Moreover, hydrogen is not the most efficient energy vector (the reason for which we continue to rely on fossil fuels), requires extensive new infrastructure, and remains a risky investment for private players.

Successful scale up of clean hydrogen requires a clear commitment towards decarbonization, including an accurate pricing of carbon. The recent government announcement on the phaseout of inefficient coal and a statement by METI minister in July appears to suggest that Japan will deepen deliberations towards making "renewables the main power source" and are positive sings for the development of hydrogen.

Yet scaling up and bringing costs down is still an immense challenge. Hence the reason for which there is growing international cooperation, and interest in developments in Europe notably, but also in China.

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