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Hydrogen RD&D Collaboration Opportunities: Japan

As at 18 August 2022

Australian Government
Department of Climate Change, Energy, the Environment and Water

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Citation

Benedicte Delaval, Trevor Rapson, Raghav Sharma, Will Hugh-Jones, Erin McClure, Max Temminghoff, Vivek Srinivasan (2022) Hydrogen RD&D Collaboration Opportunities: Japan. CSIRO, Australia

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Acknowledgments

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We are grateful for the time and input of the stakeholders from industry, government, academia who were consulted throughout this project and across the report series. In particular, the CSIRO project team would like to thank:

- Colleagues at CSIRO, members of the Australian Hydrogen Research Network (AHRN) and staff at the Department of Industry, Science, Energy and Resources (DISER), DFAT, Austrade who provided invaluable contributions to the report.
- CSIRO's Intellectual Property team and IP Australia who contributed the hydrogen patent analytics used in this series of reports: Greg Maloney (CSIRO), Catriona Shaw (IP Australia), Pushpika Wijesinghe (IP Australia).
- CSIRO's Science Impact & Policy team who contributed the hydrogen research publication analysis used in this series of reports: Tadro Abbott (CSIRO)
- The project Working Group who provided valuable feedback throughout the course of the project: Ben Aldham (CSIRO), Linda Stalker (CSIRO), Craig Buckley (Curtin University), Amalia Pearson (DISER).
- The CSIRO-DISER Hydrogen RD&D International Collaboration Program leadership team who provided oversight and guidance throughout the project: James Hetherington (DISER), Amalia Pearson (DISER), Patrick Hartley (CSIRO), Vicky Au (CSIRO), Dan O'Sullivan (CSIRO).

Finally, we would like to thank the following organisations and individuals for their time and feedback on this country report:

CSIRO: Amelia Fyfield, Doki Yamaguchi, Greg Maloney, Joel Sarout, Nawshad Haque**,** Sebastian Charnock, Yuko Wakamatsu, Yunxia Yang**.**

AHRN: Andrew Dicks (Griffith University, AHRN Convenor), Peter Grubnic (Future Fuels CRC), Peter Majewski (University of South Australia)

International Stakeholders:
New Energy and Industrial Technology Development Organisation (NEDO), Japan

Contents

Executive summary: Japan

For several decades, Japan has been at the forefront of hydrogen economy development. In recent years Japan and Australia have been actively collaborating to develop international supply chains.

The *Hydrogen RD&D Collaboration Opportunities: Japan* chapter aims to enhance country-to-country engagement by providing an overview of Japan's hydrogen priorities and ecosystem. The report also includes a publication and intellectual property (IP) scan, identifying the key stakeholders in Japan actively undertaking hydrogen RD&D, both at the early research and commercialisation stages.

Japan's hydrogen strategy

Japan's hydrogen strategy is outlined across several policy documents including the *Basic Hydrogen Strategy* (2017); *Strategic Roadmap for Hydrogen and Fuel Cells* (2019); *Strategy for Developing Hydrogen and Fuel-Cell Technologies* (2019); *Strategic Energy Plan* (2021); and *Green Growth Strategy Through Achieving Carbon Neutrality in 2050* (2021).

Japan's hydrogen strategy is driven by its '3E+S energy trilemma' – energy security, environmental sustainability, economic affordability, and safety. Japan's strategic hydrogen industry priorities are in developing and commercialising power generation turbines, carrier vessels, water electrolysis, ammonia and other carriers, hydrogen reduction in steelmaking, and international supply chains (for hydrogen import). Although already commercial, improvements and further deployment of fuel cells and refuelling infrastructure, as well as technology export in this area is also a priority.

Japan's targets and RD&D priorities

Japan's targets for 2030 are to supply 3 million tonnes of hydrogen a year (including imports and ammonia), reduce the landed cost of hydrogen to JPY 30/Nm^3 and the cost of power generation to (JPY 17 per kWh, as well as achieve several ambitious targets in terms of ammonia co-firing in industry and deployment of stationary fuel cells, fuel cell electric vehicles and refuelling infrastructure.

Japan's targets for 2050 are to supply 20 million tonnes of hydrogen a year (including imports and ammonia), reduce the landed cost of hydrogen to JPY 20/Nm^3, reduce the cost of power generation to JPY 12/kWh, achieve 50% or more ammonia co-firing and start single-fuel firing across industry. Japan also seeks to move from the consumption of hydrogen derived from fossil fuels without carbon abatement to hydrogen derived from renewables or fossil fuels with CCS. In line with this, Japan targets complete replacement of traditional residential energy systems, gas stations and conventional fossil fuel cars, buses and forklifts with systems and vehicles powered by hydrogen.

To achieve these goals, Japan is investing in RD&D in a variety of areas.

Production
Electrolysis: solid oxide, anion exchange membrane
Fossil Fuel Conversion: coal gasification with CCS
Photochemical and photocatalytic
Electrolysis: nuclear

Storage and distribution
Compression and liquefaction
Chemical storage: ammonia, liquid organic hydrogen carriers, synthetic fuels

Utilisation
Gas blending: gas separation
Transport: fuel cells and refuelling stations
Electricity generation: hydrogen turbines, ammonia turbines, fuel cells (PEM, SOFC, emerging)
Industrial processes: steel processing, synthetic fuels, methanol production
Other: carbon recycling

Cross-cutting
Lifecycle and supply chain analysis
International standards and regulations
Rare metals processing and manufacturing

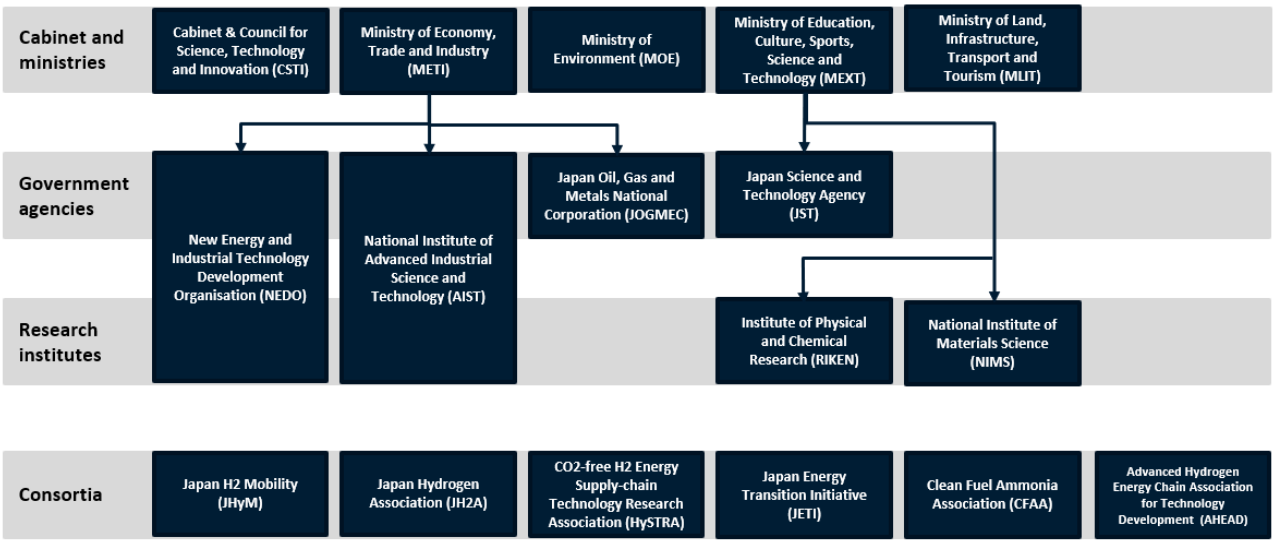
Japan's domestic hydrogen landscape

Major government bodies undertaking hydrogen activities in Japan are the METI and the New Energy and Industrial Technology Development Organisation (NEDO). METI developed the National Green Growth Strategy and the Basic Hydrogen Strategy, and implements hydrogen policy. NEDO controls and approves funding for hydrogen projects under Japan's Green Innovation Fund.

Major public funding agencies for hydrogen projects are NEDO and METI, and to a lesser extent the Ministry of Environment (MOE). The Green Innovation Fund has committed JPY 2 trillion over a 10-year period, as well as stimulation of private research and development (R&D) and investment worth JPY 15 trillion, and tax incentives of JPY 1.7 trillion over a 10-year period. Major private funding bodies are the Japan Bank for International Cooperation (JBIC) and Nippon Export and Investment Insurance (NEXI) who provide investment loans and insurance products for companies seeking to finance green innovation projects.

Japan also has a number of highly active consortia of industry-government and research, namely the CO_2-free Hydrogen Energy Supply Chain Technology Research Association (HySTRA), Advanced Hydrogen Energy Chain Association for Technology Development (AHEAD), Clean Fuel Ammonia Association (CFAA), Japan Hydrogen Association (J2HA), Japan Energy Transition Initiative (JETI), and Japan H2 Mobility (JHyM).

Figure 1: Japan's hydrogen RD&D ecosystem



Industry, academia and government are collaborating to bring about hydrogen clusters (also known as hydrogen valleys, hubs or ecosystems). These clusters are hydrogen value chain demonstrations and pilot projects that cut across sector applications. The three major clusters of integrated hydrogen value chain activity in Japan are shown in Figure 2.

Figure 2: Japan's hydrogen clusters

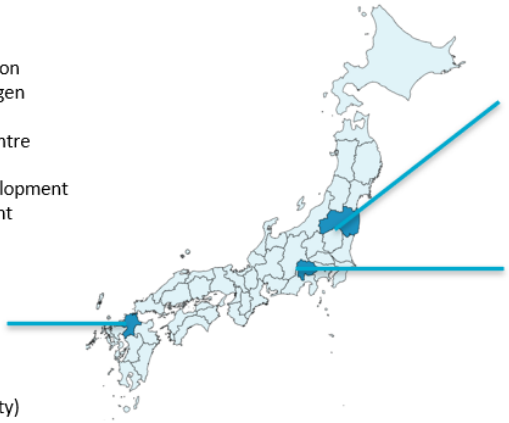
Fukuoka

Key RD&D Infrastructure:

- Kyushu University (several laboratories on campus including world's largest hydrogen research facility)
- Hydrogen Energy Test and Research Centre (HyTReC)
- Centre for Research Activities and Development of Large-scale pressure vessel equipment (CRADLE)
- QPIT: Kyushi University Platform of Interdisciplinary Energy Research

Key Demonstration Projects:

- "Hydrogen Highway"
- Kyushu Station
- "Fukuoka Hydrogen Town" (Itoshima City)
- "Hydrogen Town" Kitakyushu City
- "Demonstration of Hydrogen Generation from Sewage Biogas Source"



Fukushima

Key Demonstration Projects:

- Fukushima Hydrogen Energy Research Field (FH2R)

Yamanashi

Key RD&D Infrastructure:

- Electric Power Storage Technology Research Site
- Clean Energy Research Centre
- Fuel Cells Nanomaterials Center
- Fuel Cell Evaluation / Testing Facility (Yamanashi Industrial Technology Centre)
- Hydrogen Technology Center for HRSs

Adapted from Arias J (2019) Hydrogen and Fuel Cells in Japan. EU-Japan Centre for Industrial Cooperation

IP and publications scan

Several universities, public research institutions and private companies are highly active in early-stage hydrogen research and late-stage technology commercialisation. This is reflected in hydrogen research publication output and patent output data.

Table 1: Top organisations active in early-stage and late-stage hydrogen RD&D

Rank	Top organisations (Research publication output)	Top organisations (Hydrogen patent output)
1	Kyushu University	Panasonic Intellectual Property Management
2	Kyoto University	Toyota Motor
3	University of Tokyo	Panasonic
4	AIST (National Institute of Advanced Industrial Science and Technology)	Honda Motor
5	Tohoku University	JX Nippon Oil & Energy

International collaboration

In the *Strategic Road Map for Hydrogen and Fuel Cells*, Japan has signalled intent to collaborate on international supply chain development, governance, regulation and standardisation, and information sharing. Japan has several formalised relationships with other countries at the national level (between governments) and has engaged in major supply chain demonstration projects (mainly industry collaborations with some co-financing from governments). Japan also collaborates on hydrogen technologies via bilateral and multilateral R&D partnerships under the Strategic International Collaborative Research Program (SICORP), part of the Japan Science and Technology Agency (JST). Finally, Japan's Green Innovation Fund can provide an avenue for collaboration where Japanese organisations may be eligible to partner with international organisations or researchers on hydrogen RD&D projects.

Activity levels for hydrogen and net-zero initiatives is high. While effort has been made to capture major announcements and key information as at 18 August 2022, the content is intended to provide a starting point for informing international engagement, particularly when used in conjunction with other reports in the series, and is non-exhaustive.

1 Country analysis: Japan

1.1 Introduction

For several decades, Japan has been at the forefront of hydrogen economy development, which initially begun in the areas of automotive and stationary fuel cells. Driven by global decarbonisation efforts and domestic challenges such as energy security, and its comparative advantages in technology, Japan has published a comprehensive set of long-term strategies to 2050 that will shape energy sector activity in the next 10 years. These range from the *6th Strategic Energy Plan*[1] announced in October 2021, through to specific hydrogen and fuel cell roadmaps. Japan has set ambitious targets, namely in power generation and fuel cell deployment, and is also exploring international hydrogen value chains in order to meet its domestic hydrogen demand. To reach its targets, Japan has developed its *Green Growth Strategy,*[2] which includes the establishment of the Green Innovation Fund to provide funding for decarbonisation efforts with explicit mention of hydrogen technologies. Other avenues for collaboration include investment loans, research programs, and joint commercial research, development and demonstration (RD&D) projects.

Strategy implementation in Japan is supported by extensive RD&D[3] funding programs, as well as subsidies for the commercial uptake of more mature hydrogen technologies (e.g. stationary fuel cells). As a result, Japan has already delivered world-leading hydrogen research projects, deployed pioneering demonstration projects domestically and internationally, and has invested in low-emission technologies both in-country and abroad. Many RD&D programs are occurring domestically, in particular around the hydrogen RD&D clusters located in Fukuoka, Fukushima, and Yamanashi. Japan also has a number of joint RD&D initiatives with other countries, several of which are with Australia. While Japan has invested significantly in low-emission technologies in Australia, there are several avenues to further develop RD&D collaboration between Australia and Japan.

The *Hydrogen RD&D Collaboration Opportunities: Japan* report presents an overview of the hydrogen RD&D landscape in Japan, starting from the national strategy level, down to activity in specific hydrogen technology areas.

1.2 Japan's hydrogen drivers, strategy and RD&D priorities

1.2.1 Japan's key drivers

Japan's hydrogen strategy is primarily driven by the '3E+S energy trilemma' – energy security, environmental sustainability, economic affordability, and safety. In particular, Japan has identified energy security and self-sufficiency and CO_2 emissions reductions as key challenges they wish to overcome through hydrogen.[4] Japan's energy self-sufficiency rate is the second lowest among the OECD countries, as 94% of its primary energy supply is sourced from imported fossil fuels.[5] Regarding CO_2 emission reductions, under

[1] Agency for Natural Resources and Energy (2021) Strategic Energy Plan. Ministry of Economy, Trade and Industry (METI). https://www.enecho.meti.go.jp/en/category/others/basic_plan/

[2] Secretariat of the Committee on the Growth Strategy (2021) Green Growth Strategy Through Achieving Carbon Neutrality in 2050. Ministry of Economy, Trade and Industry (METI). https://www.meti.go.jp/english/policy/energy_environment/global_warming/ggs2050/pdf/ggs_full_en1013.pdf

[3] As defined by the IEA Guide to Reporting Energy RD&D Budget/Expenditure Statistics, 2011

[4] Ministerial Council on Renewable Energy, Hydrogen and Related Issues (2017) Basic Hydrogen Strategy, Ministry of Economy, Trade and Industry (METI)

[5] Ministerial Council on Renewable Energy, Hydrogen and Related Issues (2017) Basic Hydrogen Strategy, Ministry of Economy, Trade and Industry (METI)

the Paris Agreement Japan has stipulated that they will cut greenhouse gas emissions by 46% by FY2030 in comparison to FY2013 levels, through domestic greenhouse gas emissions reductions and absorption.[6] In particular, Japan has identified the power generation sector as a key opportunity to reach this target, as it accounts for 40% of their total CO_2 emissions.[7] Further, Japan committed to net zero emissions by 2050 in October 2020.[8]

1.2.2 Japan's strategic hydrogen industry priorities

Japan has outlined several strategic priorities they will pursue to build their hydrogen industry. At a high level, Japan has identified power generation turbines, hydrogen reduction steeling making, carrier vessels, water electrolysers, and ammonia and other carriers as key priorities in the *Green Growth Strategy*.[9] Within the transport and manufacturing areas, Japan has placed emphasis on fuel cell vehicles, ships, construction machinery, and hydrogen-powered aircraft.[10]

Specifically, with regards to strengthening international competitiveness, Japan has outlined its focus on hydrogen power generation turbines, commercial fuel-cell vehicles including fuel-cell trucks, and hydrogen reduction steelmaking.[11] These were chosen on the basis that Japanese companies possess advanced technologies in these areas.

Japan's hydrogen targets

Japan's 2017 *Basic Hydrogen Strategy*[12] and 2021 *Green Growth Strategy*[13] reports articulate hydrogen targets in production and end-use applications. This includes driving the cost of hydrogen production to levels comparable to natural gas, and targets for hydrogen volumes, power generation, hydrogen stations, and mobility. The key targets for each of these priorities for Japan is outlined in Table 2. Japan has also articulated additional ambitions as follows:

- **Production and procurement:** to commercialise power-to-gas systems by around 2032 and commercialise hydrogen power generation and international hydrogen supply chains.
- **Carriers, storage and distribution:** to demonstrate a liquid hydrogen supply chain by mid-2020s and commercialise this pathway by around 2030. Japan also seeks to establish basic technologies for a liquid organic hydrogen carrier (LOHC) supply chain by FY2020 and commercialise these technologies in 2025 and beyond.

[6] Ministry of Foreign Affairs of Japan (2021) Prime Minster Suga's attendance at the Leaders Summit on Climate. Foreign Policy https://www.mofa.go.jp/ic/ch/page6e_000236.html

[7] Ministerial Council on Renewable Energy, Hydrogen and Related Issues (2017) Basic Hydrogen Strategy. Ministry of Economy, Trade and Industry (METI)

[8] METI (2020) Japan's Roadmap to "Beyond-Zero" Carbon. https://www.meti.go.jp/english/policy/energy_environment/global_warming/roadmap/

[9] METI (2021) Green Growth Strategy. https://www.meti.go.jp/english/policy/energy_environment/global_warming/ggs2050/pdf/ggs_full_en1013.pdf

[10] METI (2021) Green Growth Strategy. https://www.meti.go.jp/english/policy/energy_environment/global_warming/ggs2050/pdf/ggs_full_en1013.pdf

[11] METI (2021) Green Growth Strategy. https://www.meti.go.jp/english/policy/energy_environment/global_warming/ggs2050/pdf/ggs_full_en1013.pdf

[12] Ministerial Council on Renewable Energy, Hydrogen and Related Issues (2017) Basic Hydrogen Strategy, Ministry of Economy, Trade and Industry (METI)

[13] METI (2021) Green Growth Strategy. https://www.meti.go.jp/english/policy/energy_environment/global_warming/ggs2050/pdf/ggs_full_en1013.pdf

- **Utilisation:** to adopt its 20% ammonia co-firing technology in coal-fired power plants through 2030, increase this ratio to 50% or more in the 2030s and start single-fuel firing in the 2040s.[14] Furthermore, the Japanese steel industry is targeting the reduction of CO_2 emissions from blast furnace steelworks by 30% using hydrogen, via the COURSE50 project.[15] In its 2021 Energy Policy, Japan plans to transition its energy mix, with hydrogen and ammonia to make up 1% of power generation by 2030; and to use hydrogen, synthetic methane and synthetic fuels in non-power industries.[16]

Table 2: Japan's hydrogen targets[17]

	Present	2030 target	2050 target
Hydrogen supply volume*	~2 million tonnes per year (incl. ammonia)	3 million tonnes per year (incl. ammonia)	20 million tonnes per year (incl. ammonia)
Landed Cost	100 JPY/Nm3	30 JPY/Nm3	Less than 20 JPY/Nm3
Stationary Fuel Cells	380,000 units installed (2021)	3 million Ene-farm units	Complete replacement of traditional residential energy systems
Power generation	97.3 JPY/kWh (2021)	17 JPY/kWh	12 JPY/kWh
	Co-firing technology 20% ammonia in coal plants developed	Expansion of 20% co-firing across industry	50% or more co-firing ratio in 2030s and start single-fuel firing in 2040s
Hydrogen stations	154 (2021)	~ 1,000	Replacement of gas stations
FCVs	4,100 (2021)	800,000 (2030 target)	Replacement of conventional fossil fuel cars
FC buses	100 (2021)	1,200	Replacement of conventional fossil fuel buses
FC forklifts	250 (2020)	10,000	Replacement of conventional forklifts

***Amount produced and procured from international supply chains, including carriers and ammonia for direct use**

[14] METI (2021) Green Growth Strategy. https://www.meti.go.jp/english/policy/energy_environment/global_warming/ggs2050/pdf/ggs_full_en1013.pdf https://www.meti.go.jp/english/press/2020/pdf/1225_001b.pdf

[15] Challenge Zero (n.d.) Realizing "Zero Carbon Steel" through Hydrogen Reduction Iron-making Technology https://www.challenge-zero.jp/en/casestudy/550; COURSE50 (2021) Technology https://www.course50.com/en/technology/

[16] METI (2021) Outline of Strategic Energy Plan. Updated on Nov 26, 2021. https://www.enecho.meti.go.jp/en/category/others/basic_plan/pdf/6th_outline.pdf

[17] Conversion rate Nm3 to kg 0.08988; METI (2017) Basic Hydrogen Strategy. https://www.meti.go.jp/english/press/2017/1226_003.html; METI (2021) Green Growth Strategy Through Achieving Carbon Neutrality in 2050 https://www.meti.go.jp/english/press/2020/pdf/1225_001b.pdf; METI (2019) The Strategic Road Map for Hydrogen and Fuel Cells https://www.meti.go.jp/english/press/2019/pdf/0312_002b.pdf; NeV (2021) Hydrogen stations for FCVs <http://www.cev-pc.or.jp/suiso_station/>; Nagashima M (2020) Japan's Hydrogen Society Ambition: 2020 Status and Perspectives, Notes de l'Ifri, IFRI, https://www.ifri.org/sites/default/files/atoms/files/nagashima_japan_hydrogen_2020.pdf; MFAT (New Zealand) (2020) Japan: Strategic Hydrogen Roadmap Market Report https://www.mfat.govt.nz/assets/Trade-General/Trade-Market-reports/Japan-Strategic-Hydrogen-Roadmap-30-October-2020-PDF.pdf; Kumagai T and Wang F (2021) Commodities 2021: Japan to enter new era of hydrogen in 2021 with launch of liquefied transport https://www.spglobal.com/platts/en/market-insights/latest-news/electric-power/122320-commodities-2021-japan-to-enter-new-era-of-hydrogen-in-2021-with-launch-of-liquefied-transport; Ohira E (2021) NEDO: R&D activities and its strategy based on the current status and policy on hydrogen energy (translated from Japanese). The Japan Planning Institute seminar (Seminar No: 15367), 2021 March 15, Tokyo, Japan.

1.2.3 Japan's hydrogen RD&D priorities

Table 3 illustrates Japan's RD&D priorities across the value chain and is broken down by supply chain area. The table outlines sub-technology areas identified by Japan and the corresponding key RD&D priorities under that area. Several of these priorities were first outlined in March 2019 in *The Strategic Roadmap for Hydrogen and Fuel Cells*.[18] In September of that year, Japan further described ten technological development priorities that require RD&D focus to achieve their 2030 and 2050 targets (outlined above) in the *Strategy for Developing Hydrogen and Fuel-Cell Technologies.*[19] In June 2021, Japan also articulated a number of hydrogen RD&D areas in its *Strategic Energy Plan.*[20]

Table 3: Japan's hydrogen RD&D priorities[21]

Supply chain area	Sub-technology areas	Japan's key RD&D priorities
Production	Electrolysis	Improve efficiency, cost, durability and scale of water electrolysis systems. Expand demonstrations in designated regions. Components related to hydrogen production at high temperature (nuclear).
	CCS	Reduce the cost of CO_2 capture, collection and storage. Reach demonstration stage of CO_2 storage technology. Establish monitoring technology for CCS.
	Brown coal gasification	Increase scale and efficiency of brown coal gasification (including CO_2 separation and collection).
	Emerging hydrogen production technologies	Highly efficient water electrolysis (e.g. solid oxide electrolysis), and photocatalysis, reversible systems, and permeable membranes to improve the purity of hydrogen.
Storage and distribution	Liquid hydrogen	Scaling-up of liquid hydrogen tanks and improving thermal insulation properties. Large-capacity liquid hydrogen loading systems. Large-capacity liquid hydrogen vaporisers, boosting pumps, piping and joints. Practical use, commercialisation and cost reduction of liquid hydrogen. Improvements in the efficiency of hydrogen liquefication (liquefier structure, non-contact bearings). Reducing the amount of carbon fibre in hydrogen storage systems in mobility applications.
	Hydrogen carriers	Practical use, commercialisation and cost reduction of energy carriers such as LOHCs, ammonia and synthetic methane.

[18] METI (2019) The Strategic Road Map for Hydrogen and Fuel Cells https://www.meti.go.jp/english/press/2019/pdf/0312_002b.pdf

[19] METI (2019) Strategy for Developing Hydrogen and Fuel-Cell Technologies https://www.meti.go.jp/press/2019/09/20190918002/20190918002-1.pdf (In Japanese).

[20] METI (2021) Outline of Strategic Energy Plan. Updated on Nov 26, 2021. https://www.enecho.meti.go.jp/en/category/others/basic_plan/pdf/6th_outline.pdf

[21] Japan's Key RD&D Priorities derived from: METI (2019) The Strategic Roadmap for Hydrogen and Fuel Cells, and Arias J (2019) Hydrogen and Fuel Cells in Japan. EU-Japan Centre for Industrial Cooperation. Australia's Key RD&D priorities derived from: Bruce S et al (2018) National Hydrogen Roadmap, CSIRO.

Supply chain area	Sub-technology areas	Japan's key RD&D priorities
		Dehydrogenation of energy carriers (e.g. process optimisation utilising waste heat). Driving down cost of the methanation processes. Cost reduction of LOHC supply chain, and reducing the loss rate of toluene.
	Compressed gas	Developing technology for reducing the amount of carbon fibre in hydrogen storage systems in mobility applications.
Utilisation	Gas turbines	Feasibility studies on limited mixture co-firing rates for hydrogen power generation (development of burners, boilers and turbines). Priority for co-firing ammonia and coal in the short term, and ammonia for gas turbines in the mid-term. Combustion improvements (higher efficiency combustors, dealing with high combustion temperatures, NO_x emissions, flame propagation velocity, flame quenching distance). Next generation, high efficiency thermal power via hydrogen co-firing. Burners and large-size, high performance boilers designed for hydrogen combustion.
	Industrial use	Investigation of utilisation and supply potential of CO_2-free hydrogen in industry (including steelmaking and oil refining). Practical application of carbon recycling technology.
	Fuel cells	Automotive fuel cells – increasing performance of membranes for cost reduction in fuel cell vehicles; reducing the amount of platinum used in electrode catalysts. Stationary fuel cells – achieving grid parity in commercial and industrial use; higher efficiency and power density; eliminating causes of degradation; increased power generation efficiency for SOFC (solid oxide fuel cells) and fuel heat utilisation factor for PEMFC (polymer electrolyte membrane fuel cell). This includes pure hydrogen fuel cells. Auxiliary machines and tank related systems.
	Hydrogen refuelling stations	Reducing cost of compressors and high-pressure vessels (e.g. polymer materials, life-extension methods for ground storage vessels, higher temperature refuelling methods). Low-cost equipment for ultra-high pressure hydrogen stations.
Cross-cutting	Lifecycle/supply chain analysis	CO_2 emissions reductions.
	International standards and regulation	Promote international standardisation in the fields of CO_2 separation, collection, transportation and storage. Promote international collaboration on safety (standards and technical improvements). Formulation of international rules for marine transportation of liquid hydrogen in the International Maritime Organisation.
	Rare metals processing and manufacturing	Mass production techniques for rare metals as catalysts

1.3 Japan's hydrogen RD&D ecosystem

1.3.1 Regulatory bodies and policy ecosystem

Overview of Japan's STI policy landscape:[22]

Japan's overall science technology and innovation (STI) policy is top-down, with centre-of-government bodies providing direction, coordination, and targets. This is accompanied by precise and 'hands-on' style planning and implementation. The Council for Science, Technology and Innovation (CSTI) under the Cabinet office (CAO) plays a 'command-tower' role, with the mandate to coordinate STI bodies and remit over ministerial budgets and STI budget allocations. Agencies and STI programs are tasked with the implementation of the strategies via research and development (R&D). Japan's STI policy is complex, made up of ministries (and 'siloed' STI areas within ministry portfolios), and integrated STI 'headquarters' leading thematic areas of science and technology.[23]

While Japan's STI governance is predominantly top-down, it is particularly skilled at coordination and consultation across different government bodies and stakeholder groups. Japan's STI system is organised such that policy officers in ministries and central government are mobile in a way that enhances communication and cooperation within a vast network of STI institutions. Large national institutes such as RIKEN (the designated national research and development institute), the National Institute for Materials Science (NIMS) and the National Institute of Advanced Industrial Science and Technology (AIST) are important in steering STI priority areas.

Japan also adopts an inclusive consultation process, involving academia, government and industry stakeholders (called San-Kan-Gaku) in a number of areas, and in the preparation of Japan's strategy documents such as the 'Basic Plans'. This has also been done under New Energy and Industrial Technology Development Organisation (NEDO) projects and Japan Society for the Promotion of Science (JSPS), providing a linkage between universities and industry. There are also numerous public-private sectoral coordination platforms and consortia (for example, the Fuel Cell Commercialisation Conference of Japan [FCCJ] led by the private sector with participation of the public sector).

Japan's hydrogen policy landscape

While Japan's high level national STI strategies, or 'Basic Plans', are directed by the CSTI/CAO, the more specific renewable energy and hydrogen specific strategies and roadmaps are drafted at the ministerial level by the Ministry of Economy, Trade and Industry (METI). Japan's hydrogen policies are captured in their strategy documents regarding hydrogen; these documents are the 2017 *Hydrogen Basic Strategy*[24], the 2019 *Strategic Road Map for Hydrogen and Fuel Cells*[25], and the 2021 *Japan's Green Growth Strategy Through Achieving Carbon Neutrality in 2050*.[26] These strategies have an application-scenario focus, where strategies and goals are split up amongst uses such as mobility, stationary fuel cells, industry, and power.

In terms of implementation, the CSTI/CAO Strategic Innovation Promotion program (SIP) (2014-2018) included the Energy Carriers R&D programme. This contained hydrogen production from renewables,

[22] OECD (2021) Mission-oriented innovation policy in Japan: Challenges opportunities and future options. OECD Science, Technology and Industry Policy Papers No. 106. OECD Publishing

[23] OECD (2021) Mission-oriented innovation policy in Japan: Challenges opportunities and future options. OECD Science, Technology and Industry Policy Papers No. 106. OECD Publishing

[24] Ministerial Council on Renewable Energy, Hydrogen and Related Issues (2017) Basic Hydrogen Strategy. Ministry of Economy, Trade and Industry

[25] Hydrogen and Fuel Cell Strategy Council (2019) The Strategic Road Map for Hydrogen and Fuel Cells. Ministry of Economy, Trade and Industry

[26] METI (2021) Green Growth Strategy.

storage and distribution systems, fuel cells, ammonia synthesis and utilisation, LOHCs, and cross-cutting aspects such as safety and standards.[27] Since the program ended, the Clean Fuel Ammonia Association was created to shift the momentum from the Energy Carriers initiative of the CSTI SIP to an industry-led vehicle.[28] The bulk of public hydrogen RD&D and commercialisation efforts, however, are carried out by METI as well as some other ministries and agencies (for example, MOE, MEXT, NEDO, JST).

The key bodies involved in hydrogen RD&D and the overall system structure are depicted below in Figure 3. A more detailed description of their roles in Japan's STI system and specific hydrogen initiatives are summarised in Table 4. Details of funding for hydrogen (bodies providing major funding, the types of funding, and what specific hydrogen areas are targeted) will be explained in section *1.3.3 Funding mechanisms*. Section *1.4 Japan's domestic hydrogen RD&D projects* will provide details of the specific RD&D programs and their budgets. Finally, Section *1.5.3 Japan's joint international RD&D projects* will outline key RD&D projects that Japan is undertaking in partnership with other countries.

Figure 3: Summary of Japan's hydrogen policy ecosystem

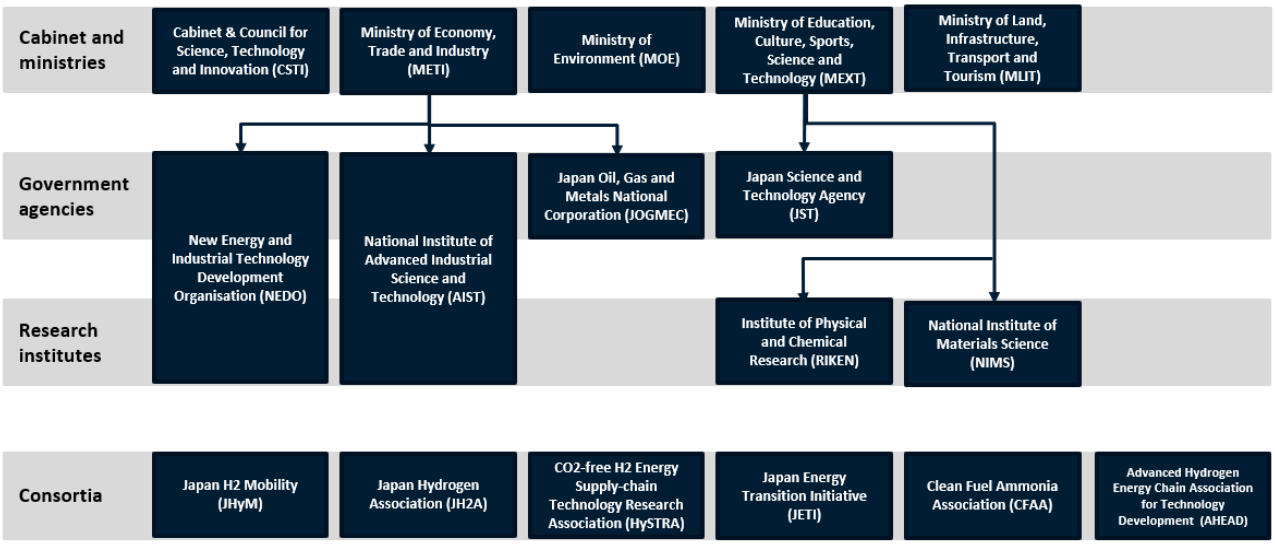


Table 4: Summary of key regulatory bodies

Body	Role in RD&D ecosystem	Hydrogen initiatives
CSTI and CAO *Council for Science, Technology and Innovation* *Cabinet Office*	'Control tower' for Japan's STI system, horizontal coordination of ministries and STI Headquarters. Develops national strategy documents. Intervenes in and reviews STI budget allocations. Direct governance over Japan's major STI programs (SIP, 'Moonshots' and PRISM).	Develops the national level 'Basic Plans'. Approved the Strategic Energy plan underpinning the strategic hydrogen roadmaps drafted by METI.
METI	Develops strategy for more specific areas.	Developed the National Green Growth Strategy and Basic Hydrogen Strategy.

[27] Cabinet Office (2015) Cross-ministerial Strategic Innovation Promotion Program (SIP): Energy Carriers. https://www.jst.go.jp/sip/pdf/SIP_energycarriers2015_en.pdf

[28] Crolius S H (2020) Green Ammonia consortium: A Force for Ammonia Energy. https://www.ammoniaenergy.org/articles/green-ammonia-consortium-a-force-for-ammonia-energy/

Body	Role in RD&D ecosystem	Hydrogen initiatives
Ministry of Economy, Trade and Industry	Direction over industrial policy generally, including industrial science and technology policy. Runs the Japan Patent Office and provides funding for RD&D projects through NEDO, the AIST and sometimes JOGMEC.	Established Council for Strategy for Hydrogen and Fuel Cells (responsible for producing strategic hydrogen and fuel cell plans). Promotes Japan's strategic hydrogen plans. Implements hydrogen policy, e.g., the commercial hydrogen refuelling subsidy program. Launched the Asia Energy Transition Initiative (AETI), which includes hydrogen and committed financial support.
MEXT *Ministry of Education, Culture, Sports, Science and Technology*	Direction over the science system. Provides funding for RD&D projects through universities, the JST, RIKEN and NIMS.	Direction of international hydrogen collaborative R&D projects under the Strategic International Collaborative Research Program (SICORP).
MOE *Ministry of Environment*	Ministry responsible for environmental conservation and pollution control.	Provides funding and support for a number of hydrogen demonstration projects across many municipalities and precincts, usually in partnership with industry stakeholders.
MLIT *Ministry of Land, Infrastructure, Transport and Tourism*	Ministry responsible for national infrastructure planning, transportation and social capital development.	MLIT published a roadmap to zero emissions in international shipping in 2020, identifying hydrogen as a key option.[29] MLIT will commercially launch prototypes for hydrogen and ammonia in shipping between 2028-2030.[30] Within the ministry, the National Institute for Land and Infrastructure Management (NILIM) has been involved in demonstration projects such as the Hydrogen production from waste treatment plant in Fukuoka.[31] The MLIT has also provided some subsidies for fuel cell vehicles, for example for taxi operators.[32]
JST	JST is consulted in the process of formulating R&D strategy, but is primarily	Joint implementation international hydrogen R&D projects with partner countries under SICORP.

[29] Nagashima M (2020) Japan's Hydrogen Society Ambition: 2020 Status and Perspectives, Notes de l'Ifri, IFRI, https://www.ifri.org/sites/default/files/atoms/files/nagashima_japan_hydrogen_2020.pdf

[30] Nagashima M (2020) Japan's Hydrogen Society Ambition: 2020 Status and Perspectives, Notes de l'Ifri, IFRI, https://www.ifri.org/sites/default/files/atoms/files/nagashima_japan_hydrogen_2020.pdf

[31] Arias J (2019) Hydrogen and Fuel Cells in Japan. EU-Japan Centre for Industrial Cooperation. https://www.eu-japan.eu/sites/default/files/publications/docs/hydrogen_and_fuel_cells_in_japan.pdf

[32] Arias J (2019) Hydrogen and Fuel Cells in Japan. EU-Japan Centre for Industrial Cooperation. https://www.eu-japan.eu/sites/default/files/publications/docs/hydrogen_and_fuel_cells_in_japan.pdf

Body	Role in RD&D ecosystem	Hydrogen initiatives
Japan Science and Technology Agency	concerned with implementation of R&D policy. JST runs a number of programs and works with industry and research institutes to implement STI strategy. Manages international collaborations and industry-academia collaboration and technology transfer (offices in USA, China, France, Singapore).	
NEDO *New Energy and Industrial Technology Development Organisation*	Japan's largest RD&D management organisation. METI funding for RD&D activities is channelled through NEDO for implementation. NEDO is also involved in policy formulation with METI and national government. NEDO acts as an innovation accelerator, working with industry, universities and public research institutes to promote technology application. It is also involved in international promotion and expansion of Japanese technology (offices located in Silicon Valley and Washington USA, China, France, India, and Thailand).	Controls and approves of funding for hydrogen projects under the Japanese Green Innovation Fund. Implements and funds hydrogen RD&D projects with aims to achieve 2030 and 2050 targets, such as the 'Development of Technologies for Realizing a Hydrogen Society' project, the 'Development of Technologies for Hydrogen Refueling Stations', and the 'Advancement of Hydrogen Technologies and Utilisation Project'.
JOGMEC *Japan Oil, Gas and Metals National Corporation*[33]	Government body providing Japanese, oil, gas and metals companies with financial and technical assistance.	Launched the Carbon Neutral Initiative, under which sits three basic policies and an action plan. One of these initiatives is 'strengthening efforts for decarbonised fuels and technology', which includes hydrogen and CCS. Has issued bids and requests for proposals related to hydrogen industry development.
AIST *National Institute of Advanced Industrial Science and Technology*	The AIST is funded through METI, and conducts interdisciplinary research to implement government STI strategy. The AIST also conducts basic early-stage research that can lead to breakthroughs.	Joint development of demonstration projects with industry partners. The Fukushima Renewable Energy Institute within AIST has a focus on hydrogen through their Hydrogen Energy Carrier Team and the Hydrogen and Heat Utilisation System Team.
RIKEN	RIKEN is funded through MEXT and is the designated national research and development institute.	Performs hydrogen research through their Hydrogen Energy Storage Technology Laboratory, Biofunctional Catalyst Research Team, Photonics Control Technology Team,

[33] Name likely to change in October 2022 https://www.jogmec.go.jp/news/release/news_10_00022.html

Body	Role in RD&D ecosystem	Hydrogen initiatives
	RIKEN conducts basic research through to applied R&D, for the implementation of national STI priorities.	and Discrete Event Simulation Research Team.
NIMS *National Institute for Materials Science*	NIMS is funded through MEXT, and is dedicated to the synthesis, characterisation and application of materials for the implementation of national STI priorities.	Advanced materials play an important role in the development and improvement of technologies. Relevant hydrogen applications span from nano-materials for fuel cells and catalysts, to bulk-scale materials for storage and transportation.

1.3.2 Hydrogen consortia

Outside of government ministries and agencies, hydrogen RD&D activity in Japan is also undertaken by peak bodies and consortia of industry, public and research stakeholders. Projects undertaken by these bodies are often closer to demonstration and commercialisation stages rather than early-stage R&D. Table 5 outlines the key hydrogen peak bodies and consortia in Japan.

Table 5: Hydrogen consortia

Consortium	Description
Hydrogen and Fuel Cell Strategy Council *previously Fuel Cell Commercialisation Conference of Japan (FCCJ)*	The Hydrogen and Fuel Cell Strategy Council is an advisory body made up of experts, industry representatives and government. It develops the roadmaps and strategies for fuel cells and hydrogen, which are promoted by METI.[34]
HySTRA *CO_2-free Hydrogen Energy Supply-chain Technology Research Association*	HySTRA is comprised of Iwatani, Kawasaki Heavy Industries, Shell Japan, J-Power (Electric Power Development Co Ltd), Marubeni, and JXTG Nippon Oil & Energy.[35] HySTRA is supported by NEDO and was established to implement a demonstration of an international supply chain for transportation of hydrogen to Japan in the form of liquid hydrogen (LH2). The initial pilot project produces hydrogen from brown coal gasification in the Latrobe Valley, Australia.[36]
CFAA *The Clean Fuel Ammonia Association*	The Clean Fuel Ammonia Association, formerly the Green Ammonia Consortium, is an international body operating out of Japan, comprised of 120 members from industry, government and research institutes.[37]

[34] METI (2014) METI has compiled a Strategic Road Map for Hydrogen and Fuel Cells [Press Release]. https://www.meti.go.jp/english/press/2014/0624_04.html

[35] Fuel Cells Bulletin (2019) HySTRA developing green hydrogen supply chain tech in Japan. Fuel Cells Bulletin, DOI: 10.1016/S1464-2859(19)30381-5

[36] Fuel Cells Bulletin (2019) HySTRA developing green hydrogen supply chain tech in Japan. Fuel Cells Bulletin, DOI: 10.1016/S1464-2859(19)30381-5

[37] Clean Fuel Ammonia Association (2022) Home. https://greenammonia.org/en/

Consortium	Description
	Established to continue momentum in energy carriers after the SIP Energy Carriers programme ceased in 2018, the Clean Fuel Ammonia Association is focused on building 'a value chain from supply to use of CO_2-free ammonia.'[38]
JH2A *Japan Hydrogen Association*	JH2A is a peak body promoting the creation of a Japanese hydrogen supply chain. It is comprised of 226 companies as at July 2021, including chairs and vice chairs Toyota Motor Corp, Iwatani, Sumimoto Mitsui Financial Group, ENEOS Holdings Inc, KHI, Toshiba and Mitsui.[39]
JETI *Japan Energy Transition Initiative*	JETI is a collaboration between Japanese and international organisations dedicated to accelerating the energy transition among business, finance and policy makers in Japan.[40]
JHyM *Japan H2 Mobility*	JHyM is a consortium of companies and the Development Bank of Japan (owned by the Government of Japan through the Minister of Finance) seeking to build 80 hydrogen refuelling stations by 2021 under the guidance of the Ministerial Council on Renewable Energy, Hydrogen and Related Issues.[41] The consortium will continue to provide financial support for the development and operation of hydrogen stations until 2027.[42]
AHEAD *Advanced Hydrogen Energy Chain Association for Technology Development*	AHEAD comprises Chiyoda Corporation, Mitsubishi Corporation, Mitsui & Co Ltd and Nippon Yusen Kabushiki Kaisha. AHEAD is leading a project supported by NEDO to implement a demonstration project to build an international supply chain for transportation of hydrogen to Japan in the form of methylcyclohexane (MCH), a LOHC.[43]
Kobe/Kansai Area Hydrogen Council	Launched in 2020, the Kobe/Kansai Area Hydrogen Council aims to develop hydrogen utilisation methods and establishing a hydrogen supply chain in the Kobe/Kansai area.[44] The council is led by Marbubeni Corporation, and comprises KHI, JPOWER, Iwatani Corp, Kansai Electric Power Co., K Line, Mitsubishi power, Shell Japan, ENEOS, Deloitte and Panasonic.
Chubu Area Hydrogen Council	Launched in 2020, the Chubu Area Hydrogen Council is a hydrogen utilisation study group which aims to promote and expand hydrogen utilisation to build a supply chain in the Chubu region. The group comprises Idemitsu, Iwatani, ENEOS, Sumitomo Corp, Chubu Electric Power Co, Toho Gas, Toyota, Air Liquide, Nippon Steel, SMBC and Mitsubishi chemical.[45]

[38] Ammonia Energy Association (2020) Green Ammonia Consortium: A Force for Ammonia Energy. https://www.ammoniaenergy.org/articles/green-ammonia-consortium-a-force-for-ammonia-energy/

[39] JH2A (2021) Organisational Chart https://www.japanh2association.jp/en/; Japan Hydrogen Association (2021) Membership List https://www.japanh2association.jp/en/pdf/20210727_membership_list.pdf

[40] JETI (2021) About. JETI. https://jeti.eco/about-us

[41] JHyM (n.d.) About JHyM. <https://www.jhym.co.jp/nav-about/>

[42] Nagashima M (2020) Japan's Hydrogen Society Ambition: 2020 Status and Perspectives, Notes de l'Ifri, IFRI, https://www.ifri.org/sites/default/files/atoms/files/nagashima_japan_hydrogen_2020.pdf

[43] AHEAD (2021) Research. https://www.ahead.or.jp/en/research.html

[44] Marbubeni (2020) Launch of New Hydrogen Utilisation council in Kobe/Kansai area https://www.marubeni.com/en/news/2020/release/00010.html

[45] Hydrogen Utilization Study Group in Chubu (2021) Hydrogen Utilization Study Group in Chubu. Press Release https://www.sumitomocorp.com/africa/-/media/Files/hq/news/release/2021/14390/1.pdf?la=en

1.3.3 Funding mechanisms

Overview of Japan's hydrogen public budget allocations[46]

In general, the CSTI (under the CAO) is responsible for setting STI budgets for Japan. The CSTI allocates budget over its own STI programs such as the Cross Ministerial Strategic Innovation Promotion Programme (SIP) of roughly JPY 28 billion in 2018, and the 'Moonshot' Research and Development Program of roughly JPY 100 billion in 2018 and JPY 15 billion additional funding in 2019. The Ministries allocate 4% of their budgets to the implementation of the SIP programs. These funding mechanisms span the entirety of Japan's national missions and R&D priorities (not just hydrogen). A large proportion of public R&D funding is allocated to universities via 'block funding',[47] however universities are becoming increasingly independent from MEXT and increasingly rely on competitive grants funding.[48]

For hydrogen specifically, the CSTI/CAO funded the SIP initiative's Energy Carrier program from 2014-2018. However, as shown in Figure 4 the bulk of public funding for hydrogen comes from METI, while the Ministry of Environment also provides funding and support for the development of regional hydrogen supply chains with local renewable resources .[49] METI's funding for hydrogen related research, feasibility studies and pilot projects are often provided through NEDO as well as Japan Oil, Gas and Metals National Corporation (JOGMEC).[50] It should be noted that most NEDO projects (particularly pilot projects), require endorsement and commercialisation plans from industrial partners in order to successfully pass stage-gate decisions.

Funding for hydrogen follows a two-pronged approach as outlined in 'Japan's Green Growth Strategy through Achieving Carbon Neutrality in 2050'.[51]

- **Grant Funding:** both the Green Innovation Fund of roughly JPY 2 trillion over a 10-year period, and an additional JPY 15 trillion in measures to stimulate private R&D and investment towards carbon neutrality.
- **Tax incentives:** provided by the government, which aims to stimulate roughly JPY 1.7 trillion worth of private investment over a 10-year period.

Figure 4 summarises the trends in public funding for hydrogen in Japan. As hydrogen technologies have become more mature (in particular residential fuel cells, fuel cell vehicles and refuelling stations), funding has shifted from RD&D to subsidy funding. Subsidy funding for residential fuel cells (ENE-FARM[52]) have reduced as costs have come down over time, while current subsidies continue to support fuel cell vehicles and refuelling infrastructure. A breakdown of RD&D funding shows that Japan's RD&D investment in recent years has been dedicated to integrated supply chains. In 2021 some funding was also allocated to the industrial sector, namely decarbonising industrial activities and developing environmentally friendly steelmaking processes. Current public funding programs for hydrogen RD&D, and international eligibility to participate are listed in Table 6.

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[46] OECD (2021) Mission-oriented innovation policy in Japan: Challenges opportunities and future options. OECD Science, Technology and Industry Policy Papers No. 106. OECD Publishing

[47] Block funding is government funding via grants to approved providers, which are attached to a range of conditions.

[48] Competitive grants funding occurs where R&D is solicited via an RFP (request for proposal), and applicants compete to obtain these.

[49] Linklaters (2021) Capturing the hydrogen opportunity for Japan and Australia. Linklaters https://www.linklaters.com/en/insights/thought-leadership/asia-pacific-renewable-energy-insights-2020/capturing-the-hydrogen-opportunity-for-australia-and-japan

[50] Linklaters (2021) Capturing the hydrogen opportunity for Japan and Australia. Linklaters https://www.linklaters.com/en/insights/thought-leadership/asia-pacific-renewable-energy-insights-2020/capturing-the-hydrogen-opportunity-for-australia-and-japan

[51] METI (2021) Green Growth Strategy.
https://www.meti.go.jp/english/policy/energy_environment/global_warming/ggs2050/pdf/ggs_full_en1013.pdf

[52] Nagashima M (2018) Japan's Hydrogen Strategy and Its Economic and Geopolitical Implications. IFRI.
https://www.ifri.org/sites/default/files/atoms/files/nagashima_japan_hydrogen_2018_.pdf

Figure 4: Trends for public hydrogen funding in Japan[53]

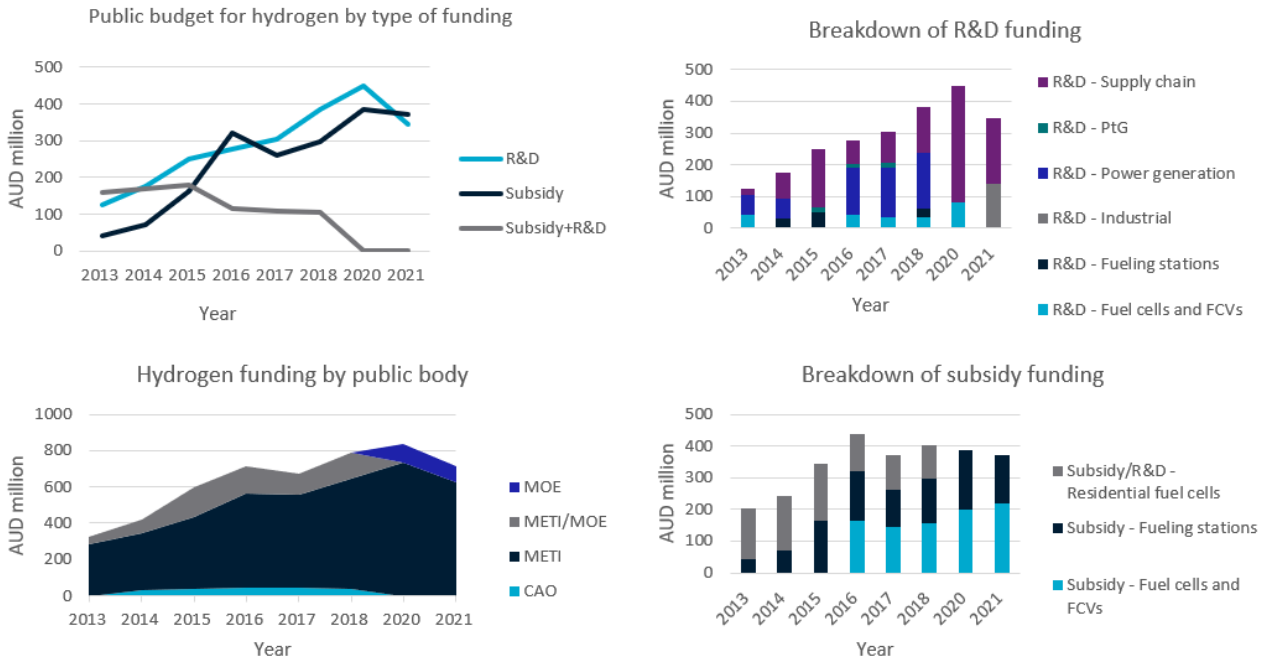

Table 6: Public funding for hydrogen RD&D

Provider	Funding mechanism	International eligibility to participate
METI	**Asia Energy Transition Initiative (AETI):**[54] in May 2021, Japan announced it would present ASEAN countries with a package of concrete support measures based on the following 5 pillars: • Support for the development of energy transition roadmaps • Presentation and promotion of the Asian version of the transition finance • JYP 1.1 trillion financial support for renewable energy, energy efficiency, liquid natural gas (LNG) and other projects (including hydrogen) • Support for technology development and demonstration using the benefits of the JPY 2 trillion fund (includes hydrogen) • Human resource development on decarbonisation technologies and knowledge sharing through the Asia CCUS network	Only ASEAN countries are eligible for funding. No data available on non-ASEAN participation.
METI	**Green Innovation Fund:** as above, the Green Innovation Fund is a roughly JPY 2 trillion fund set up by METI to support projects promoting decarbonisation.	Yes. Where companies/ researchers partner with a Japanese organisation.[55]

[53] Figure excludes data from year 2019. Figures derived from data sources: Nagashima M (2018) Japan's Hydrogen Strategy and Its Economic and Geopolitical Implications. IFRI. https://www.ifri.org/sites/default/files/atoms/files/nagashima_japan_hydrogen_2018_.pdf and Ministry of Environment (2021) Hydrogen Supply Chain Platform https://www.env.go.jp/seisaku/list/ondanka_saisei/lowcarbon-h2-sc/en/index.html; Conversion rate based on annual average closing price for each year www.macrotrends.net

[54] METI (2021) Minister Kajiyama announced the Asia Energy Transition Initiative (AETI). https://www.meti.go.jp/english/press/2021/0528_002.html

[55] ENEOS (2021) ENEOS Begins Joint Study with Origin for Development of a Japan-Australia CO2-free Hydrogen Supply Chain in Queensland. Press Release. https://www.eneos.co.jp/english/newsrelease/2021/pdf/20210823_01.pdf

Funding for international hydrogen RD&D

The JST has also created a funding program for joint and multilateral RD&D under the SICORP program.

Provider	Funding mechanism	International eligibility to participate
JST	**SICORP:** this is an initiative executed by the JST to contribute solutions to national and international challenges and to bolster Japan's science and technology capabilities through international collaboration. An example is the EIG CONCERT-Japan 8th Joint Call. This call invited Japan and Europe-based researchers to develop more efficient, reliable, flexible and clean hydrogen-based technologies. Participating countries from Europe are Bulgaria, Czech Republic, France, Germany, Hungary, Lithuania, Norway, Poland, Slovakia, Spain, Switzerland, and Turkey.[56] For more details on how to engage with respect to the SICORP mechanism and projects see *Section 1.5.3 Japan's joint international RD&D projects.*	Yes. Where a bilateral/multilateral agreement is in place.[57]

Private funding for hydrogen RD&D

Funding for hydrogen also comes from Japan's public finance institutions such as the Japan Bank for International Cooperation (JBIC) and Nippon Export and Investment Insurance (NEXI).

JBIC has expressed a desire to support and be involved in the development of Japan's hydrogen society by providing supplementary funding to private sector funds. In a cabinet order in January 2020, the eligible sectors for JBIC funding increased to now include support through export loans and overseas investment loans in hydrogen production, transport, supply and use projects in developed countries.[58]

NEXI has a loan insurance product for green innovation, where Japanese companies can finance projects related to environmental protection and climate change prevention. They have also signed a Memorandum of Understanding (MoU) with the European bank for Reconstruction and Development to combine their green financing expertise.[59]

Provider	Funding mechanism	International eligibility to participate
JBIC	**Overseas Investment Loans:** these loans support Japanese foreign direct investments and can be provided to Japanese companies, overseas Japanese affiliates and foreign governments or financial institutions that have equity participations in or provide loans to such overseas affiliates. The eligible sectors for these loans include hydrogen.[60]	Yes. Where the entity is either affiliated with a Japanese firm (e.g. joint venture), has equity participation in or provides loans to Japanese affiliates.[61]

[56] JST (2021) Strategic International Collaborative Research Program (SICORP) EIG CONCERT-Japan 8th Joint Call: Sustainable Hydrogen Technology as Affordable and Clean Energy https://www.jst.go.jp/inter/english/program_e/announce_e/announce_hydrogen2021.html

[57] JST (n.d.) Strategic International Collaborative Research Program: Program Setup https://www.jst.go.jp/inter/english/sicorp/structure.html

[58] Bocobza J and Touch C (2021) Hydrogen and Japan. Project Finance https://www.projectfinance.law/publications/2021/april/hydrogen-and-japan/

[59] Bocobza J and Touch C (2021) Hydrogen and Japan. Project Finance https://www.projectfinance.law/publications/2021/april/hydrogen-and-japan/

[60] JBIC (n.d.) Overseas Investment Loans https://www.jbic.go.jp/en/support-menu/investment.html

[61] JBIC (n.d.) Overseas Investment Loans https://www.jbic.go.jp/en/support-menu/investment.html

1.3.4 Other key hydrogen policies, regulation and legislation

In addition to the governance, strategy and funding mechanisms for hydrogen RD&D programs, Japan has several key policies, regulations and laws to incentivise and regulate the commercial uptake of hydrogen technologies. Notable policies and regulations are outlined below.

Legislation

The *Gas Business Act* and the *High-Pressure Gas Act* regulate hydrogen infrastructure and businesses. The operation of both laws may restrict how hydrogen can be produced, stored, distributed and utilised. [62]

The *Gas Business Act,* which regulates hydrogen when it is distributed through pipelines, outlines minimum safety standards and registration requirements for business operators. Many of the provisions relate to the safe operation of distribution pipelines; for example, conformity with technical standards, notification to METI of construction plans and the appointment of a chief gas engineer. [63]

The *High-Pressure Gas Safety Act* applies to the supply of hydrogen and is not specific to distribution via pipelines. The *High-Pressure Gas Safety Act defines* hydrogen as a high-pressure gas and therefore, sets out various obligations for the production, storage and utilisation of hydrogen. A summary of notable provisions and key implications for hydrogen under the Act are as follows: [64]

- Approval from the prefectural governor is required to manufacture or store hydrogen.
- The storage, production and transportation of hydrogen is subject to technical regulations and standards established in the legislation's supporting regulatory guidance.
- Hydrogen refuelling stations must align with the technical standards set out in the legislation.

Other notable laws and regulations which may relate to the commercial uptake of hydrogen include: [65]

- The *Ministerial Ordinance on the Arrangement of Facility Districts for New Business Facilities,* which establishes minimum technical and physical design specifications for commercial-scale hydrogen facilities; and
- The *Regulation for Enforcement of the Air Pollution Control Act,* which requires hydrogen production facilities to periodically measure and notify local governments of soot, smoke and NO_x emissions.

Whilst comprehensive legal analysis is beyond the scope of this paper, METI has acknowledged regulatory and legal uncertainty surrounding hydrogen technology. For example, it is unclear whether hydrogen terminals are subject to the same regulations as LNG terminals. This may have implications for the commercial uptake and implementation of hydrogen technology. METI is currently working to resolve these ambiguities and streamline regulations and laws applicable to hydrogen businesses to incentivise uptake.

[62] Nishimura and Asahi (2021) Recent Regulatory Developments for Utilisation of Hydrogen Energy in Japan https://www.nishimura.com/en/newsletters/natural-resources-and-energy_210611.html

[63] Nishimura and Asahi (2021) Recent Regulatory Developments for Utilisation of Hydrogen Energy in Japan https://www.nishimura.com/en/newsletters/natural-resources-and-energy_210611.html

[64] Nishimura and Asahi (2021) Recent Regulatory Developments for Utilisation of Hydrogen Energy in Japan https://www.nishimura.com/en/newsletters/natural-resources-and-energy_210611.html

[65] Nishimura and Asahi (2021) Recent Regulatory Developments for Utilisation of Hydrogen Energy in Japan https://www.nishimura.com/en/newsletters/natural-resources-and-energy_210611.html

Current policies

METI launched a subsidy program for commercial hydrogen refuelling stations in 2013. Subsidies for capital and operating expenditure depend on the type and size of the station. Capital expenditure subsidies can range from half to a third of the cost, capped between roughly JPY 10-309 million.[66] Each refuelling station can receive government funding up to 50% of the initial investment cost as well as an operating subsidy of roughly JPY 22 million per year. Tax incentivises are provided under the Green Innovation Fund. Updated figures for METI subsidy program funding for 2020 and 2021 are as follows:[67]

Subsidy programs	FY2020	FY2021
The subsidy for the introduction of clean energy vehicles	~ JPY 13 billion	~ JPY 15.5 billion
Subsidies for hydrogen station construction projects to promote fuel cell vehicles	~JPY 12 billion	~ JPY 11 billion

Refuelling station costs in Japan are much higher than in other countries. METI, along with several ministries, are proposing to deregulate laws and regulations relating to hydrogen refuelling stations to reduce the high capital expenditures and operating costs, and to accelerate development. This includes easing material requirements, lifting limits on storage volumes, easing operating procedures, legalising self-servicing, and shortening distance requirements between facilities.[68]

Tax and subsidies

Japan has implemented a carbon tax. The tax is expected to incentivise the development and commercial-scale uptake of renewable energy technologies, including hydrogen.[69]

Similarly, Japan's 2021 tax reform bill was enacted in March 2021, under which certain investments qualify for tax incentives. This bill includes carbon neutral tax incentives for investments in manufacturing processes and products that reduce greenhouse gas emissions and support decarbonisation efforts; offering a tax credit of up to 10%, or 50% special depreciation, for investments of up to JPY 50 billion.[70]

Future policy considerations

Updates to the 'Green Growth Strategy through achieving Carbon Neutrality' in June 2021 highlight Japan's hydrogen regulation priorities. Under these changes, specific action plans were noted for priority energy and industry sectors to encourage structural changes, and a greater emphasis was placed on adapting corporate R&D policies by revising policy measures and goals.[71]

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[66] NEV (2021) Outline of Reiwa 3rd year "Fuel cell vehicle hydrogen supply facility installation assistance project". Subsidy Information http://www.cev-pc.or.jp/hojo/suiso_outline_r03.html; NEV (2021) Outline of "Fuel Cell Vehicle New Demand Creation Activity Subsidy Project" in Reiwa 3. Subsidy information. http://www.cev-pc.or.jp/hojo/suiso_outline_juyo_r03.html

[67] MOE (2021) Summary of Japan's Hydrogen Strategy https://www.env.go.jp/seisaku/list/ondanka_saisei/lowcarbon-h2-sc/PDF/Summary_of_Japan's_Hydrogen_Strategy.pdf

[68] Nagashima M (2020) Japan's Hydrogen Society Ambition: 2020 Status and Perspectives, Notes de l'Ifri, IFRI, https://www.ifri.org/sites/default/files/atoms/files/nagashima_japan_hydrogen_2020.pdf

[69] Gokhale H (2021) Japan's Carbon Tax Policy: Limitations and Policy Suggestions. Current Research in Environmental Sustainability. DOI: 10.1016/j.crsust.2021.100082

[70] EY (2021) Japan's 2021 Tax Reform introduces tax incentives for carbon neutrality and digital transformation. Viewed at https://www.ey.com/en_gl/tax-alerts/japan-s-2021-tax-reform-introduces-tax-incentives-for-carbon-neutrality-and-digital-transformation

[71] METI (2021) Green Growth Strategy. https://www.meti.go.jp/english/policy/energy_environment/global_warming/ggs2050/pdf/ggs_full_en1013.pdf

Japan has also begun to consider a number of other policies such as promoting trade and use of clean hydrogen[72] through green electricity certificates and the existing J-Credit mechanism used for carbon credits and offsets, or by incorporating clean hydrogen in the existing emission reduction laws for power generators.[73] Specifically, METI and MOE announced in July 2021 that they will consider to incorporate CO_2 reduction technologies – including hydrogen, ammonia, and CCUS – into J-Credit.[74] The J-Credit system will also be extended indefinitely rather than culminating in FY2030 as previously expected. In addition, the MOE has formulated guidelines to calculate the carbon footprint of hydrogen supply chains.[75]

Japan is also examining the potential of strengthening the role of JOGMEC in risk financing for decarbonised fuels and decarbonisation technologies (hydrogen, ammonia, and CCS).[76]

1.4 Japan's domestic hydrogen RD&D projects

1.4.1 Major domestic hydrogen RD&D projects

Projects led by government bodies

NEDO/METI Projects

Current projects of NEDO involve driving hydrogen demand and integrating hydrogen with Japan's existing energy system. This includes realising large-scale hydrogen supply chains and equipment for hydrogen applications and industrial use. NEDO efforts also centre on developing system technologies and electrolysis technologies to aid with the hydrogen transition.[77]

NEDO have a number of projects (Table 7) that they have announced regarding hydrogen:

Table 7: NEDO Fuel Cell and hydrogen R&D projects

Project	FY2022 Budget	Period
Innovative Hydrogen Technology Development Program This program addresses basic and fundamental technology development related to next generation hydrogen production, storage, and utilization.	JPY 1.3 billion	2014-2022
Advanced Fuel Cell Technology Development Program This program aims to realize a fuel cell system with high efficiency, high durability, and low cost. In this program, new fuel cell material development, evaluation /	JPY 7.9 billion	2020-2024

[72] While Japan does not have a national certification system for hydrogen, hydrogen that is produced using renewable energy or by fossil fuel conversion with carbon emissions offset using Japan's Green Energy Certificates or J-Credits, can apply to receive a 'low-carbon' certificate from governors of some prefectures. Hydrogen produced in this manner is considered clean or low-carbon hydrogen. See Nishimura & Asahi (2022) Hydrogen update and outlook in Japan 2022, Lexology. https://www.lexology.com/commentary/energy-natural-resources/japan/nishimura-asahi/hydrogen-update-and-outlook-in-japan-2022

[73] Nagashima M (2020) Japan's Hydrogen Society Ambition: 2020 Status and Perspectives, Notes de l'Ifri, IFRI, https://www.ifri.org/sites/default/files/atoms/files/nagashima_japan_hydrogen_2020.pdf

[74] The Energy Conservation Centre & the Asia Energy Efficiency and Conservation Collaboration Centre (2021) J-Credit to cover Hydrogen. Viewed at https://www.asiaeec-col.eccj.or.jp/policynews-202106-3/

[75] Nagashima M (2020) Japan's Hydrogen Society Ambition: 2020 Status and Perspectives, Notes de l'Ifri, IFRI, https://www.ifri.org/sites/default/files/atoms/files/nagashima_japan_hydrogen_2020.pdf

[76] METI (2021) Outline of Strategic Energy Plan. Updated on Nov 26, 2021. https://www.enecho.meti.go.jp/en/category/others/basic_plan/pdf/6th_outline.pdf https://www.jogmec.go.jp/news/release/news_10_00022.html

[77] NEDO (2021) Presentation by the International Affairs Department NEDO to CSIRO, October 28 2021.

Project	FY2022 Budget	Period
reaction analysis technology development, and system demonstration are conducted		
Ultrahigh-Pressure Hydrogen Infrastructure Development Program To further dissemination of hydrogen refuelling stations, this program aims to develop technologies and regulations, code and standard that will reduce the maintenance and operating costs of hydrogen refuelling stations.	JPY 3.1 billion	2018-2022
Hydrogen Energy System Development Program To realize a large-scale hydrogen supply chain, this program is working on the development of large-scale hydrogen utilization technology such as hydrogen gas turbine, long-distance hydrogen transportation technology, and power-to-gas technology. In addition, efforts are being made to develop local hydrogen utilization models.	JPY 10.4 billion	2014-2025

Green Innovation Fund, NEDO Project Funding[78]

In August 2021, the Green Innovation Fund announced JPY 2 trillion funding to support new RD&D projects in two key areas: establishing a commercial-scale hydrogen supply chain, and hydrogen production via electrolysis using surplus renewable electricity. Funded projects are outlined in Table 8 below.

Table 8: Green Innovation Fund projects

Project	Partner(s)	Funding	Status
Demonstration of the demonstration-scale hydrogen supply chain based on LH2	Japan Hydrogen Energy; ENEOS; Iwatani	~ JPY 220 billion	2021-2029
Demonstration of the demonstration-scale hydrogen supply chain based on MCH	ENEOS	~ JPY 63 billion	2021-2030
Establishment of a foundation to evaluate materials for hydrogen liquefaction technology	NIMS	~ JPY 3 billion	2021-2025
Three separate demonstration projects of large-scale hydrogen gas turbines (pure and co-fire) - the demonstration projects will be separately undertaken by JERA, Kansai and ENEOS	Kansai; JERA; ENEOS	~ JPY 31 billion	2021-2030
Development of a large-scale alkaline water electrolyser (green chemicals)	Asahi Kasei; JGC	~ JPY 54 billion	2021-2030

[78] NEDO (2021) Green Innovation Fund Project Starts Demonstration Research Project on Hydrogen as the First Project https://www.nedo.go.jp/news/press/AA5_101471.html

Project	Partner(s)	Funding	Status
Development of a large-scale PEM electrolyser, including demonstration of power generation decarbonisation	Yamanashi Prefectural Government Corporate Bureau; TEPCO Holdings; TEPCO Energy Partner; Toray; Hitachi Zosen Co.; Siemens Energy; Miura; Kaji Tech. Co.	~ JPY 10 billion	2021-2025
Establishing a robust technique to evaluate efficiency and performance of electrolysers	AIST	~ JPY 3 billion	2021-2025
Development of next-generation aircrafts - five projects in this area were selected, of which three directly pertain to hydrogen-fuelled aircraft and hydrogen storage	KHI will lead the three relevant projects[79]	No data	2021-2030
Development of next-generation ships[80]	KHI, Yanmar Power Technology, Japan Engine Corp.; NYK, Japan Shipyard, Japan Engine Corp, IHI Power Systems; Itochu Corp., Mitsui E&S Machinery, Kawasaki Kisen Kaisha, NS United Shipping; Hitachi Zosen, Yanmar Power Technology, Mitsui OSK Lines	~JYP 35 billion[81]	2021-2030
Fuel Ammonia Supply Chain Establishment[82]	Development and demonstration of ammonia synthesis technology (CHIYODA corp., Tokyo Electric Power Company Holdings, Inc., JERA Co., Inc.) Development of green ammonia synthesis technology (Idemitsu Kosan Co., Ltd., The University of Tokyo, KYUSHU UNIVERSITY, OSAKA UNIVERSITY, Tokyo Institute of Technology)	~JYP 59.8 billion	2021-2030

[79] Global Kawasaki (2021) Kawasaki Hydrogen Aircraft Core Technology Development Project Selected for NEDO Green Innovation Fund Support, Kawasaki News. Viewed at https://global.kawasaki.com/en/corp/newsroom/news/detail/?f=20211105_3638

[80] Yanmar (2021) Japanese Manufacturers Cooperate on Development of Hydrogen Fueled Marine Engines [Press Release]. Viewed at https://www.yanmar.com/global/marinecommercial/news/2021/05/06/91508.html; IHI Power Systems Co. Ltd. (2021) Demonstration Project Begins for Commercialization of Vessels Equipped with Domestically Produced Ammonia-Fueled Engine – Utilising the Japanese Government's Green Innovation Fund. Viewed at https://www.ihi.co.jp/ips/english/all_news/20211026.html Offshore Energy (2021) K Line, partners can start with ammonia-fueled ship project. Viewed at https://www.offshore-energy.biz/k-line-partners-can-start-with-ammonia-fueled-ship-project/; Yanmar (2021) NEDO Selects Methane Slip Reduction Project for Next Generation Ship Development. Viewed at https://www.yanmar.com/global/news/2021/10/27/99066.html

[81] FuelCellsWorks (2021) Japan: Subsidizing Next-Generation Ships with 35 Billion Yen to include Hydrogen. Viewed 12 January 2022 https://fuelcellsworks.com/subscribers/japan-subsidizing-next-generation-ships-with-35-billion-yen-to-include-hydrogen/

[82] Green Innovation Fund Project "Fuel Ammonia Supply Chain Construction" Started https://www.nedo.go.jp/news/press/AA5_101502.html https://www.nedo.go.jp/content/100940967.pdf

Project	Partner(s)	Funding	Status
	Demonstration project for ammonia co-firing at a large-scale commercial coal-firing plant at JERA's Hekinan Thermal Power Station (IHI Corporation, JERA Co., Inc.) Demonstration of high ratio co-combustion burners (Mitsubishi Heavy Industries, Ltd., JERA Co., Inc) Development of single fuel combustion burners (IHI Corporation, TOHOKU UNIVERSITY, AIST)		

METI Projects

METI has invested roughly JPY 70 billion in 2020 and JPY 70.7 billion in 2021 in subsidies for hydrogen and fuel cells, as well as RD&D projects. Table 9 shows the major RD&D projects undertaken in 2020 and 2021.

Table 9: METI RD&D Projects[83]

Project	Stage	Budget	Period
Development of environmentally friendly steelmaking process technology	R&D	~ JPY 2.8 billion	FY2021

Ministry of Environment Projects

The MOE has supported several demonstration projects from 2019-2021 (Table 10). In addition to this, the MOE also supports R&D initiatives such as self-sustained and decentralised hydrogen energy supply systems, various utilisation technologies, and applications in transport and vehicles.[84]

Table 10: Ministry of Environment (MOE) Demonstration Projects [85]

Project	Partner(s)	Status
Hydrogen utilisation promotion project derived from renewable energy for building a carbon free society ~ JPY 6.58 billion.[86]	Not specified	Budgeted for FY2021

[83] MOE (2020) Projects for the Creation of a Hydrogen Society https://www.env.go.jp/seisaku/list/ondanka_saisei/lowcarbon-h2-sc/PDF/0315-suiso_pamphlet_E.pdf; Ministry of the Environment (2021) Summary of Japan's Hydrogen Strategy https://www.env.go.jp/seisaku/list/ondanka_saisei/lowcarbon-h2-sc/PDF/Summary_of_Japan's_Hydrogen_Strategy.pdf

[84] MOE 2020) Projects for the Creation of a Hydrogen Society https://www.env.go.jp/seisaku/list/ondanka_saisei/lowcarbon-h2-sc/PDF/1108_suiso_pamphlet_E.pdf

[85] Arias J (2019) Hydrogen and Fuel Cells in Japan. EU-Japan Centre for Industrial Cooperation. https://www.eu-japan.eu/sites/default/files/publications/docs/hydrogen_and_fuel_cells_in_japan.pdf; Ministry of the Environment (2020) Projects for the Creation of a Hydrogen Society https://www.env.go.jp/seisaku/list/ondanka_saisei/lowcarbon-h2-sc/PDF/1108_suiso_pamphlet_E.pdf

[86] MOE (2021) Summary of Japan's Hydrogen Strategy https://www.env.go.jp/seisaku/list/ondanka_saisei/lowcarbon-h2-sc/PDF/Summary_of_Japan's_Hydrogen_Strategy.pdf

Project	Partner(s)	Status
Demonstrate green hydrogen production and supply using local renewable energy in Kitakyushu City	Kitakyushu Power Co. Ltd, IHI Corp., Fukuoka Oxygen Co. Ltd., ENEOS Corp.	Started in FY2020
Construct and demonstrate a low-cost renewable hydrogen supply chain using an operation optimization system	Obayashi Corp.	Started in FY2020
The hydrogen energy supply chain demonstration project from livestock manure	Air Water Inc., Kajima Corp, Nippon Steel Pipeline & Engineering Co Ltd, Air Products Japan	Completed FY2021
Build a model of regional cooperation and local energy production/consumption using high purity waste hydrogen from caustic soda production	Tokuyama Corp., Tosoh Crop.	Completed FY2021
Low-carbon hydrogen demonstration project of a waste plastic regional circular model	Showa Denko	Completed FY2021
Demonstrate a low-carbon hydrogen supply chain using fuel cells and the existing logistics network in Tomiya, Miyagi Prefecture	Hitachi Ltd, Marubeni Corp., Miyagi Corp.	Completed FY2021
Demonstrate the production of hydrogen from electrolysis using wind power and its energy storage, as well as the supply and use of hydrogen mixed with municipal natural gas	NTT Data Institute of Management Consulting Inc., Dainichi machine and Engineering Co, Ltd.	Completed FY2021
Demonstrate a low-pressure hydrogen delivery system to promote hydrogen use in buildings and city infrastructure	Taisei Corp., Kyushu University, Muroran Institute of Technology, Tomoe Shokai Co. Ltd., The Japan Steel Works Ltd., Kita Koudensha Corp.	Completed FY2021
Introduction of fuel cell forklift at Keihin coast Area and demonstration of clean hydrogen utilisation model construction	Toyota Motor Crop.	Completed FY2020
Expanding the use of hydrogen produced from a small hydropower plant and establishing a hydrogen utilisation model suitable for the local characteristic of Hokkaido	Toshiba ESS, Iwatani Corp.	Completed FY2020

Projects by other Government Bodies:

- In March 2020, AIST demonstrated an MCH carrier and completed domestic renewable supply chain demonstration in Fukushima in 2020 in partnership with Hitachi and Denyo Kosan.[87] See *Section 1.5.3* for details of Chiyoda's application of MCH carrier technology in international supply chain demonstrations.
- The Ministry of Land, Infrastructure, Transport and Tourism (MLIT) plans to prototype four options to decarbonise shipping. Hydrogen and ammonia are one of the options and commercial launch of each prototype is expected between 2028-2030.[88]

Projects by consortia[89]

- In 2021 INPEX announced plans to expand its energy business to include production and supply of hydrogen. This will include carbon-free hydrogen production from natural gas reforming with CCUS. INPEX and its partners have announced plans to demonstrate its CCUS technology on its onshore fields in Niigata, using enhanced oil recovery (EOR) technology (CO_2 foaming) currently being developed. INPEX has also announced intent to enhance R&D activities to establish a hydrogen value chain, in collaboration with other industry stakeholders. Further INPEX is evaluating ammonia and liquid hydrogen for transportation of hydrogen produced at INPEX assets overseas.[90]
- In 2021 JERA and IHI (under NEDO's support) announced the commencement of a demonstration project for ammonia co-firing at a large-scale commercial coal-firing plant at JERA's Hekinan Thermal Power Station, to be completed by FY2024.[91]
- In 2021 Toyota announced it will be demonstrating its first race car, a Toyota Corolla, with a hydrogen combustion engine at the Super Taikyu Race in Autopolis.[92]
- In 2020, Tokyo Gas and Miura Kogyo began testing the demonstration of an industrial SOFC system of 5 kW scale.[93]
- Mitsubishi Power (ex. Mitsubishi Hitachi Power Systems) developed a hybrid system of SOFC (called MEGAMIE), and are demonstrating SOFC-Micro Gas Turbines (MGT) hybrid systems at university campuses, factories and commercial buildings.[94] Mitsubishi Power is also developing gas turbines for hydrogen and for ammonia combustion.[95]

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[87] AIST (2020) Demonstration of a Hydrogen Supply Chain and a Hydrogen Co-firing Engine Generator System. https://www.ifri.org/sites/default/files/atoms/files/nagashima_japan_hydrogen_2020.pdf>

[88] Nagashima M (2020) Japan's Hydrogen Society Ambition: 2020 Status and Perspectives, Notes de l'Ifri, IFRI, https://www.ifri.org/sites/default/files/atoms/files/nagashima_japan_hydrogen_2020.pdf

[89] Nagashima M (2020) Japan's Hydrogen Society Ambition: 2020 Status and Perspectives, Notes de l'Ifri, IFRI, https://www.ifri.org/sites/default/files/atoms/files/nagashima_japan_hydrogen_2020.pdf

[90] INPEX (2021) Corporate Position on Climate Change. https://www.inpex.co.jp/english/csr/climatechange/pdf/20210216.pdf

[91] JERA (2021) JERA and IHI to Start a Demonstration Project Related to Ammonia Co-firing at a Large-Scale Commercial Coal-Fired Power Plant. https://www.jera.co.jp/english/information/20210524_677

[92] Toyota (2021) Hydrogen Engine-equipped Corolla to Enter Super Taikyu Race in Autopolis. https://global.toyota/en/newsroom/corporate/35790602.html

[93] Nagashima M (2020) Japan's Hydrogen Society Ambition: 2020 Status and Perspectives, Notes de l'Ifri, IFRI, https://www.ifri.org/sites/default/files/atoms/files/nagashima_japan_hydrogen_2020.pdf

[94] Nagashima M (2020) Japan's Hydrogen Society Ambition: 2020 Status and Perspectives, Notes de l'Ifri, IFRI, https://www.ifri.org/sites/default/files/atoms/files/nagashima_japan_hydrogen_2020.pdf

[95] Patel S (2021) Mitsubishi Power Developing 100% Ammonia-Capable Gas Turbine. PowerMag, https://www.powermag.com/mitsubishi-power-developing-100-ammonia-capable-gas-turbine/

- Mitsubishi Heavy Industries are testing 100% hydrogen combustion engines jointly with the AIST.[96]
- Kawasaki Heavy Industries demonstrated the first electricity (1,100 kW) and heat (2,800 kW) supply to an urban area using 100% hydrogen with a 1MW turbine in April 2018. Subsequently Kawasaki successfully tested a 700 MW turbine using 30% hydrogen.[97] Commercial operation of two of these turbines will begin in 2025 with a view to increase hydrogen concentration to 100% by 2045 and bring down NO_x emissions.[98]
- In June 2021, Kawasaki Heavy Industries, Ltd released their *Group Vision 2030*[99] which outlined several demonstration and commercial-scale hydrogen projects. First, Kawasaki was party to the above MoU with Iwatani Corporation to produce and liquefy hydrogen from renewable energy and import to Japan. Second, Kawasaki is developing core technologies and infrastructure necessary for commercialisation of the hydrogen supply chain. This includes a liquefaction and loading terminal and a liquid hydrogen carrier vessel that can maintain temperatures of below -253°C to ensure hydrogen is retained in its denser, liquified state.[100] In addition, Kawasaki is undertaking hydrogen RD&D across the value chain, with a focus on hydrogen power generation, fuel cell vehicles (rolling stock, motorcycles, passenger vehicles) and aircraft.[101]
- For major joint RD&D projects with Australia and other countries (such as the HESC project) see section *1.5 International collaboration and joint RD&D projects.*

1.4.2 Major domestic commercial hydrogen projects

The scope of this report is on research, development and demonstration (RD&D) projects. For information on commercial hydrogen projects, see *HyResource*, an online knowledge sharing platform across the hydrogen community led by CSIRO, Future Fuels CRC, NERA and the Australian Hydrogen Council.

HyResource provides a directory of publicly available databases and information sources on international projects:

- https://research.csiro.au/hyresource/projects/international/

[96] Mitsubishi Heavy Industries (2021) MHIET Conducts combustion Test for Hydrogen Engine with Pure Hydrogen: Joint Project with AIST to Achieve Stable Combustion of 100% Hydrogen Fuel for a Carbon-free, Hydrogen Economy. https://www.mhi.com/news/210121.html

[97] Nagashima M (2020) Japan's Hydrogen Society Ambition: 2020 Status and Perspectives, Notes de l'Ifri, IFRI, https://www.ifri.org/sites/default/files/atoms/files/nagashima_japan_hydrogen_2020.pdf

[98] Nagashima M (2020) Japan's Hydrogen Society Ambition: 2020 Status and Perspectives, Notes de l'Ifri, IFRI, https://www.ifri.org/sites/default/files/atoms/files/nagashima_japan_hydrogen_2020.pdf

[99] Kawasaki Heavy Industries, Ltd. (2021) Group Vision 2030 Progress Report Meeting. https://global.kawasaki.com/en/corp/ir/library/pdf/etc_210601-1e.pdf

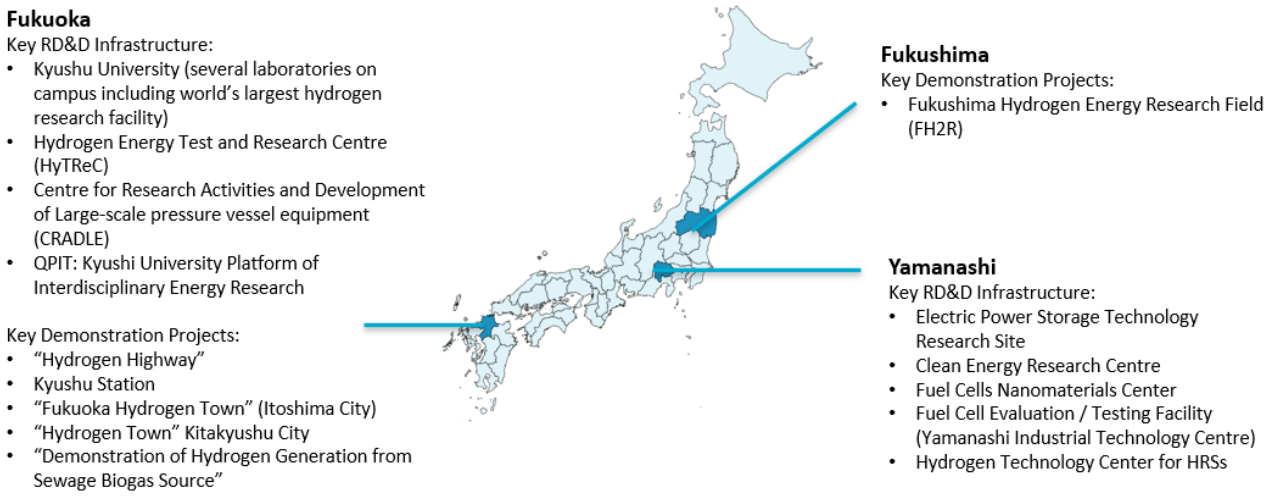
[100] Green Car Congress (2021) Kawasaki's liquefied hydrogen carrier departs to pick up first cargo. https://www.greencarcongress.com/2021/12/20211227-khi.html

[101] Kawasaki Heavy Industries, Ltd. (2021) Group Vision 2030 Progress Report Meeting. https://global.kawasaki.com/en/corp/ir/library/pdf/etc_210601-1e.pdf

1.4.3 Japan's hydrogen RD&D clusters

There are three main hydrogen clusters in Japan located in Fukuoka, Fukushima and Yamanashi. Each cluster leverages its unique comparative advantages and has set out local hydrogen strategies. Fukuoka is the "hydrogen hub of Japan" designated by METI, Fukushima is focused on becoming a renewable energy leader in light of the Fukushima disaster, and Yamanashi is focused on energy storage and becoming a 'fuel cell valley' in light of its solar resources.[102] Each cluster is comprised of universities, local government, industry stakeholders and public research institutions. Further, Japan's 2021 *Strategic Energy Plan* outlines a policy plan to transition service stations to "comprehensive energy hubs" to supply energy to electric and fuel cell electric vehicles, and "local community infrastructure" to provide services to meet local needs.[103]

Figure 5: Japan's hydrogen clusters 2019[104]



Fukuoka:[105]

- As the METI designated "hydrogen hub of Japan", Fukuoka has been supporting the development of a sustainable society based on hydrogen energy since 2004, and holds the largest hydrogen conference in Japan, the Fukuoka Strategy Conference for Hydrogen Energy.
- The key stakeholders active in the Fukuoka cluster projects include Kyushu University, Kyushi Electric Power Co., Taiyo Nippon Sanso Co., Kyuky Co, Iwatani Co., Nippon Steel Co., JXTG Nippon Oil & Energy, Saibu Gas Energy Co., Sumimoto Metal, Yawate Steel Works, Mitsubishi Kakoki Kaisha Ltd., and Toyota Tsusho Corp.
- Key initiatives include the Hy-Life Project, Fukuoka FCV Club, Q-PIT: Kyushu University Platform of Inter/Transdisciplinary Energy Research, and the Fukuoka Strategy Conference for Hydrogen Energy (~800 members across industry, university, administrative and research organisations).

[102] Arias J (2019) Hydrogen and Fuel Cells in Japan. EU-Japan Centre for Industrial Cooperation https://www.eu-japan.eu/sites/default/files/publications/docs/hydrogen_and_fuel_cells_in_japan.pdf

[103] METI (2021) Outline of Strategic Energy Plan. Updated on Nov 26, 2021. https://www.enecho.meti.go.jp/en/category/others/basic_plan/pdf/6th_outline.pdf

[104] Adapted from Arias J (2019) Hydrogen and Fuel Cells in Japan. EU-Japan Centre for Industrial Cooperation https://www.eu-japan.eu/sites/default/files/publications/docs/hydrogen_and_fuel_cells_in_japan.pdf

[105] Arias J (2019) Hydrogen and Fuel Cells in Japan. EU-Japan Centre for Industrial Cooperation https://www.eu-japan.eu/sites/default/files/publications/docs/hydrogen_and_fuel_cells_in_japan.pdf

- Key demonstration projects include the “Hydrogen Highway”, Kyushu Station, “Fukuoka Hydrogen Town” (Itoshima City), “Hydrogen Town” Kitakyushu City, and Hydrogen production from sewage sludge.
- Key RD&D infrastructure capabilities include Kyushu University (several laboratories on campus including the world’s largest hydrogen research facility), the Hydrogen Energy Test and Research Centre (HyTReC), and the Centre for Research Activities and Development of Large-scale pressure vessel Equipment (CRADLE).

Fukushima:[106]

- As an emerging global centre for renewable energy research, Fukushima has been hosting AIST activities in hydrogen energy carriers, and hydrogen and heat utilisation systems.
- Fukushima hosts a major hydrogen project called the Fukushima Hydrogen Energy Research Field (FH2R), comprising a hydrogen production facility using solar power and electrolysis, transport and storage of compressed hydrogen, and utilisation in gas networks and for electricity generation and grid balancing.
- Key stakeholders in this cluster include AIST’s Fukushima Renewable Energy Institute (FREA), Thoshiba ESS, Tohoku Electric Power Co., and Iwatani Corporation.

Yamanashi:[107]

- Positioning itself as a “Fuel Cell Valley” and national centre for storage and fuel cell development, Yamanashi hosts a number of demonstration projects within its Komekurayama Facilities. This facility includes the Electric Power Storage Technology Research Site (solar power station), and a power to gas demonstration.
- Key stakeholders contributing to projects in the Yamanashi area include Iwate Unversity, Shinshu University, Tohoku University, AIST, Yamanashi University, TEPCO, Kobe Steel Ltd, Panasonic, Toray Research Centre Inc, Takaoka Toko, HySUT, Miura, Hitz Hitachi Zosen, Japan Steel Works Ltd., Tanaka Kinkinzoku Kogyo KK, Kaneka Corp., and Nissan Arc Ltd.
- Key RD&D infrastructure in the area includes the Clean Energy Research Center, the Hydrogen and Fuel Cell Technical Support Center, the Fuel Cell Nanomaterials Center, and the Hydrogen Technical Center (HySUT).

[106] Arias J (2019) Hydrogen and Fuel Cells in Japan. EU-Japan Centre for Industrial Cooperation https://www.eu-japan.eu/sites/default/files/publications/docs/hydrogen_and_fuel_cells_in_japan.pdf

[107] Arias J (2019) Hydrogen and Fuel Cells in Japan. EU-Japan Centre for Industrial Cooperation https://www.eu-japan.eu/sites/default/files/publications/docs/hydrogen_and_fuel_cells_in_japan.pdf

1.5 International collaboration and joint RD&D projects

1.5.1 Overview of Japan's approach to international collaboration

There are several references to international collaboration in Japan's *Strategic Road Map for Hydrogen and Fuel Cells*.[108] Japan intends to collaborate on R&D particularly to help build supply chains suited to the characteristics of each region, expand production scale and reduce costs.[109] Japan also intends to engage in a broad range of collaborative activities (including RD&D) via international collaboration channels:

- **International governance:** Utilising international government frameworks (or discussing possibilities for multilateral or bilateral cooperation with other countries) to carry out information exchanges on policies, undertake joint investigations and joint research, and promoting deregulation and joint demonstration testing. Japan intends to engage with other leaders in the field (e.g. the US, Germany and France) and drive progress in areas where Japan is currently leading the world (e.g. mobility and supply chains). This includes work on safety regulations and sharing of information on matters such as accidents.
- **Developing international supply chains:** Standardisation and harmonisation of standards and regulations to reduce hydrogen supply costs and the price of products such as fuel cell vehicles. Japan intends to actively make proposals related to international standards on hydrogen such as ISO/TC197 (Hydrogen Technologies), IEC/TC105 (Fuel Cell Technologies) and UN/GTR13 (Global Technical Regulation on Hydrogen/Fuel Cell Vehicles), to promote international standardisation.
- **Information sharing:** Japan intends to publish results of demonstration tests on the building of hydrogen supply chains in Japan and share the information with other countries to strengthen international collaborations so that an international supply chain can be built. Japan also intends to actively facilitate information exchanges between the government and the private sector and actively incorporate industries' needs and policy proposals into decision-making, to strengthen collaboration between the government and the private sector on a global scale.

Japan had also conducted a survey to gather information about current, ongoing and future hydrogen projects, and related government activity in several major countries.[110]

With respect to building international supply chains, Japan's Institute of Energy Economics (IEEJ) recently released a report on 'The Economics of the Green Hydrogen International Supply Chain'.[111] The report considered hydrogen produced from renewables from Australia, Chile and the US, and hydrogen produced from fossil fuels with CCS from Australia and Saudi Arabia. The findings were as follows:[112]

- Liquified hydrogen or MCH have more extensive end use applications than ammonia, particularly to decarbonise Japan's energy system, industry and mobility.
- Liquified hydrogen or MCH produced from renewables are obtained at lowest cost from Chile and will be able to compete with hydrogen produced from fossil fuels with CCS if electrolysis costs are reduced by a third which is expected by 2030.

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[108] Hydrogen and Fuel Cell Strategy Council (2019) The Strategic Roadmap for Hydrogen and Fuel Cells, Ministry of Economy, Trade and Industry.

[109] Leader Associates (2021) Overview of The Commercial Application Path of Hydrogen Energy in Japan.

[110] US, Canada, Australia, China, Korea, Germany, France, UK, Spain, Netherlands and other EU countries; METI (2020) Reiwa 2nd year survey on measures to improve energy supply and demand structure (Confirmation of progress of hydrogen / fuel cell strategy roadmap and survey on the utilisation of hydrogen and fuel cells in Japan and overseas) Report. (In Japanese) https://www.meti.go.jp/meti_lib/report/2020FY/000252.pdf

[111] IIEJ (2021) Study on the Economics of the Green Hydrogen International Supply Chain https://eneken.ieej.or.jp/data/9882.pdf

[112] IIEJ (2021) Study on the Economics of the Green Hydrogen International Supply Chain https://eneken.ieej.or.jp/data/9882.pdf

- Ammonia produced from fossil fuels with CCS is obtained at lowest cost from Saudi Arabia.
- Shipping cost of long-distance transportation of hydrogen or ammonia does not significantly impact total supply cost.
- Ammonia produced from renewables will require further development of production technologies that can operate on intermittent energy from renewables. Further developments required are improving electrolyser capacity factor, smoothing power from intermittent renewable sources, and reducing the cost of electrolysis by providing hydrogen into the energy grid as a service.
- Collaboration between Japan and exporters will facilitate business opportunities. This requires government-to-government cooperation as well as deep involvement of academia, industry and the financial sector.

1.5.2 Japan's bilateral hydrogen relationships

Japan has several formalised relationships with international partners related to hydrogen. Major relationships are detailed in Table 11.

Table 11: Formalised relationships with other countries

Country	Relationship	Description
Malaysia	MoU	In September 2021, ENEOS-Petronas announced an MoU with a subsidiary of Malaysia's Petronas to develop a CO_2-free hydrogen supply chain in Japan. The project is part of the Japanese government's Green Innovation Fund.[113] This builds upon a previous MoU signed in March 2020 between Petronas and Japanese companies JOGMEC and ENEOS (formerly JX Nippon Oil and Gas Exploration) to study the development of Malaysia's high-CO_2 content gas fields with CCUS and the possibility of exporting natural-gas based hydrogen to Japan.[114]
Australia	MoC	In June 2021, Japan and Australia agreed to the 'Australia-Japan Partnership on Decarbonisation through Technology'. This agreement aims to collaborate on a technology-led response to greenhouse gas emissions reduction, and support the clean energy transition, growth and resilience of the Indo-Pacific region.[115] Under the partnership, in January 2022, Australia announced the first round of funding (AUD 150 million) for the Clean Hydrogen Trade Program (ACHTP) which involves the production and export of hydrogen to Japan. The ACHTP supports domestic hydrogen supply chain projects that secure foreign and/or private investment, and encourages the commercialisation of clean hydrogen and its derivative compounds that may then be exported to partnering countries.[116] In September 2021, the Quadrilateral Security Dialogue (Quad) between Australia, Japan, India and the US, discussed the establishment of a clean-hydrogen partnership. The aims of a clean-hydrogen partnership revolve around reducing

[113] ENEOS (2021) ENEOS Begins Collaborative Studies and Researchers with Petronas Group towards the development of CO_2-free hydrogen supply chain https://www.eneos.co.jp/english/newsrelease/2021/pdf/20210910_01.pdf

[114] IEA (2021) Carbon Capture, Utilisation and Storage: The Opportunity in Southeast Asia https://iea.blob.core.windows.net/assets/2c510792-7de5-458c-bc5c-95c7e2560738/CarbonCaptureUtilisationandStorage_TheOpportunityinSoutheastAsia.pdf

[115] Prime Minister of Australia (2021) Japan-Australia Partnership on Decarbonisation through Technology. Media Statement. https://www.pm.gov.au/media/japan-australia-partnership-decarbonisation-through-technology

[116] Minister for Industry, Energy and Emissions Reduction (2022) Australia Japan Clean Hydrogen Trade Partnership [Press release]. Viewed at https://www.minister.industry.gov.au/ministers/taylor/media-releases/australia-japan-clean-hydrogen-trade-partnership

Country	Relationship	Description
		costs across the hydrogen value chain; promoting technological development and the scale-up of hydrogen production; identifying and developing infrastructure to safety store, transport and utilise hydrogen across various end-use applications; and stimulating market demand across the Indo-pacific for hydrogen and hydrogen related technologies. [117] The Australian Minister for Trade, Tourism and Investment and Japanese Minister of Economy, Trade and Industry co-chaired the Japan-Australia Ministerial Economic Dialogue (JAERD) in July 2021. Along with strengthening bilateral cooperation, the two countries reaffirmed endeavours to advance existing joint projects, collaborate on zero-emissions technology RD&D, and discuss ways in which they can assist ASEAN members in a wider energy transition.[118] In 2020, METI and Department of Industry, Science, Energy and Resources (DISER) (formerly the Department of Industry, Innovation and Science [DIIS]) issued a Joint Statement on Cooperation on Hydrogen and Fuel Cells. At this event the Japan External Trade Organisation (JETRO) also signed an MoU with the Australian Trade and Investment Commission (Austrade).[119] In September 2019, METI and DISER signed a Memorandum of Cooperation (MoC) for carbon recycling related activities.[120] In the long term this includes the creation of synthetic chemicals and fuels which can be produced via hydrogen and CO_2.
UAE	MoC	April 2021, Japan and the UAE signed an MoC in the field of hydrogen. Japan and the UAE will look to cooperate on exchanging information on hydrogen policy, constructing supply chains (including hydrogen production and transportation to Japan) and exchanging information for developing regulations and standards.[121] METI signed an MoC in January 2021 with the Abu Dhabi National Oil Company (ADNOC) to encourage bilateral cooperation in the fields of fuel ammonia and carbon recycling, focusing on the demonstration of technology and expansion of the market.[122]
California (US)	MoU	The Japan Bank for International Cooperation signed an MoU in March 2021 with the State of California of the US to enhance collaboration in a wide range of areas, including global environmental protection, clean mobility, clean energy (such as hydrogen) and energy storage.

[117] The White House (2021) Fact Sheet: Quad Leader's Summit [Statements and Releases]. Fact Sheet: Quad Leaders' Summit | The White House

[118] Minister for Trade, Tourism and Investment (2021) Japan-Australia Ministerial Economic Dialogue [Joint Statement]. https://www.trademinister.gov.au/minister/dan-tehan/media-release/japan-australia-ministerial-economic-dialogue

[119] METI and DIIS (2020) Joint Statement on Cooperation on Hydrogen and Fuel Cells between the Ministry of Economy, Trade and Industry of Japan and the Department of Industry, Innovation and Science of Australia https://www.meti.go.jp/press/2019/01/20200110007/20200110007-3.pdf

[120] METI and DISER (2010) Memorandum of Cooperation on Carbon Recycling between the Ministry of Economy, Trade and Industry of Japan and the Department of Industry, Innovation and Science of Australia https://www.meti.go.jp/press/2019/09/20190927003/20190927003-12.pdf

[121] METI (2021) State Minister Ejima Signs MOC on Hydrogen with H.E. Suhail Mohamed Al Mazrouei, Minister of Energy and Infrastructure, UAE. https://www.meti.go.jp/english/press/2021/0409_001.html

[122] Bocobza J & Touch C (2021) Hydrogen and Japan. Norton Rose Fulbright. https://www.projectfinance.law/publications/2021/april/hydrogen-and-japan/

Country	Relationship	Description
Argentina	MoC	In September 2019, Japan and Argentina signed an MoC to promote hydrogen investments and develop a framework to integrate Argentina into sustainable energy global value chains.[123]
Saudi Arabia	MoU	Japan and Saudi Arabia are engaging in initial discussions to produce hydrogen from Saudi Arabia's oil resources and the shipping of blue ammonia. In July 2019 the IEEJ (Institute of Energy Economics Japan) and Saudi Aramco signed an MoU for a pre-feasibility study of carbon-free ammonia production in Saudi Arabia.[124]
USA & EU	Joint Statement	In June 2019, METI, the European Commission Directorate-General for Energy (ENER) and the Department of Energy of the United States (DOE) issued a Joint Statement of future cooperation on hydrogen and fuel cell technologies.[125]
New Zealand	MoC	Japan and New Zealand signed an MoC on hydrogen produced from renewables in 2018, which seeks to encourage industry and research institutes to collaborate in the field of hydrogen and has led to two Japanese companies investing in, or looking to invest in, hydrogen projects in NZ.[126]
Indonesia, Singapore & Thailand	MoC	METI signed MoC regarding hydrogen and ammonia with Indonesia, Singapore and Thailand in Jan 2022.[127]
USA	MoC	METI signed MoC regarding hydrogen and ammonia with USA in May 2022.[128]

1.5.3 Japan's joint international RD&D projects

Country	Projects
US	In June 2021, Jera and its subsidiary Jera Americas announced it will carry out research on carbon-free synthetic methane utilisation in its power plants in the US. The study obtained JPY 50 million from NEDO to explore the use of synthetic methane as a generation fuel in power plants. Jera is a Japanese utility company with 15 gas-fired power plants across the US and Mexico. The US location was also chosen due to the availability of low-cost renewable energy.[129] Further, Toyota Tsusho Co. and Toyota Tsusho America Inc. were selected by NEDO to conduct a feasibility study on the use of hydrogen based on a local production for local consumption model,

[123] MOFA (Argentina) (2019) Argentina and Japan work together in development of hydrogen as clean fuel. https://www.cancilleria.gob.ar/en/announcements/news/argentina-and-japan-work-together-development-hydrogen-clean-fuel

[124] Nagashima M (2020) Japan's Hydrogen Society Ambition: 2020 Status and Perspectives. IFRI https://www.ifri.org/sites/default/files/atoms/files/nagashima_japan_hydrogen_2020.pdf

[125] Crolius SH (2019) Japan, US, EU Agree to Cooperate on Hydrogen. Ammonia Energy Association. https://www.ammoniaenergy.org/articles/japan-u-s-e-u-agree-to-cooperate-on-hydrogen/

[126] New Zealand Embassy, Tokyo (2020) Japan: Strategic Hydrogen Roadmap. New Zealand Foreign Affairs and Trade.; METI (2020) Memorandum of Cooperation between the Ministry of Economy, Trade and Industry of Japan and the Ministry of Business, Innovation and Employment of New Zealand on Hydrogen. https://www.meti.go.jp/press/2018/10/20181023012/20181023012-1.pdf

[127] Minister Hagiuda visits Indonesia, Singapore, and Thailand https://www.meti.go.jp/english/press/2022/0114_001.html

[128] Minister Hagiuda visits the United States of America https://www.meti.go.jp/english/press/2022/0506_003.html

[129] Argus (2021) Japan's Jera to study carbon-free synthetic methane use https://www.argusmedia.com/en/news/2225628-japans-jera-to-study-carbonfree-synthetic-methane-use

Country	Projects
	which commenced in September 2020. This feasibility study is currently being conducted at the Port of Los Angeles, using hydrogen fuel cells to power port machinery.[130] In July 2022 Mitsui & Co., Ltd signed joint development agreement with U.S.-based CF Industries for clean ammonia production project.[131]
Saudi Arabia	In September 2020, Saudi Arabia and Japan successfully demonstrated an ammonia supply network where ammonia was produced using fossil fuels with carbon capture. The shipment was 36.3 tonnes (40 tons) of high-grade ammonia. The organisations involved were Aramco from Saudi Arabia and the Institute of Energy Economics, Japan.[132] This project was the world's first low-carbon (from fossil fuels with CCS) ammonia shipment.
Australia	At COP26, the Japan's MOE announced it has awarded funding to Marubeni Corporation for a pilot project to produce low-cost hydrogen from renewables in South Australia for export to the Indo Pacific area, including the island countries in the Pacific. [133] The hydrogen will be transported in the form of a metal hydride to Indonesia for utilisation in fuel cells and other applications in an industrial town.[134] Based on the results of the pilot, applying the same business model to other parts of Indonesia and the Indo-Pacific region may be considered.[135] This is part of Japan's ambition to build global hydrogen supply chains, and is also part of a broader program to assist developing countries transition to clean energy. South Australia was selected due to its abundance in renewables and developed infrastructure, and Marubeni Corporation is currently working with the South Australian government on site selection.[136] In September 2021, three Japanese companies and two Australian companies (Iwatani, Kawasaki, Marubeni, Kansai Electric Power, Stanwell Corporation and APT Management) signed an MoU to conduct a feasibility study into a liquified hydrogen supply chain between the Central Queensland Hydrogen Project in Aldoga and Japan. The project's objective is to produce 100 tonnes of liquid hydrogen a day by 2026 from renewables, and 800 tonnes by 2031, which will be liquified at Port Gladstone and shipped to Japan. **[137]** The Hydrogen Energy Supply Chain (HESC) **[138]** pilot project tests the supply chain from Australia to Japan, where hydrogen is produced in Latrobe Valley, Victoria, and exported to Kobe in Japan. The initiative is led by the HySTRA consortium (including Kawasaki, Iwatani, J-Power, Marubeni, Shell Japan, Sumimoto Corporation and Australia's AGL). The project received financial backing from the Australian Government, Victorian Government, and the Japanese government (METI/NEDO). The world's first hydrogen carrier ship "Suiso Frontier" was supplied by Kawasaki Heavy Industries

[130] Toyota Tsusho Corporation (2020) Toyota Tsusho to Conduct Feasibility Study into Local Production for Local Consumption of Hydrogen - Seeking to use fuel cells to large-scale machinery at the Port of Los Angeles [Press Release]. Viewed at https://www.toyota-tsusho.com/english/press/detail/201014_004696.html

[131] Mitsui signs joint development agreement with U.S.-based CF Industries for clean ammonia production project https://www.mitsui.com/jp/en/topics/2022/1243904_13410.html

[132] Aramco (2020) World's first blue ammonia shipment opens new route to a sustainable future. https://www.aramco.com/en/news-media/news/2020/first-blue-ammonia-shipment

[133] Government of South Australia (2021) Japanese government funds green hydrogen export project from South Australia. Department for Trade and Investment. https://dti.sa.gov.au/articles/japanese-government-funds-green-hydrogen-export-project-from-south-australia

[134] Marubeni Corporation (2021) Pilot Project for comprehensive Support throughout the Whole Hydrogen Supply chain. Presentation.

[135] Marubeni Corporation (2021) Pilot Project for comprehensive Support throughout the Whole Hydrogen Supply chain. Presentation.

[136] Government of South Australia (2021) Japanese government funds green hydrogen export project from South Australia. Department for Trade and Investment. https://dti.sa.gov.au/articles/japanese-government-funds-green-hydrogen-export-project-from-south-australia

[137] Reuters (2021) Japan, Australia firms look to build large-scale green liquified hydrogen supply chain. Reuters. https://www.reuters.com/business/sustainable-business/japan-australia-firms-look-build-large-scale-green-liquefied-hydrogen-supply-2021-09-15/

[138] Hashimoto M (2020) Energy Transition and Japan's Strategy for Hydrogen Society. International Symposium on CCUS, Osaka University http://www.env.go.jp/earth/ccu/Keynote%203.pdf; HESC (2021) HESC https://hydrogenenergysupplychain.com/

Country	Projects
	(construction December 2019) and set sail from Australia to Kobe, Japan in January 2022.[139] The coal gasification production facility in Victoria is also led by the consortium, as is the regasification terminal in Hyogo.[140] In 2019 JXG Nippon Oil & Energy Corporation, Chiyoda Corporation, University of Tokyo and Queensland University partnered to test electrolysis from solar PV in Australia to produce methylcyclohexane (MCH) which was then shipped and dehydrogenated in Japan.[141] In April 2021, JOGMEC called for proposals for a 'Feasibility Study on Fuel Ammonia Value Chain from Australia to Japan'. The period of the contract will conclude on March 31, 2022, and the estimated JOGMEC budget for the project is roughly JPY 200 million.[142]The successful bidders were: Marubeni Corporation, Woodside Energy Ltd, Hokuriku Electric Power Company and The Kansai Electric Power Company.[143] A consortium comprising Japan's IHI, JERA, Marubeni and Australia's Woodside Energy are jointly participating in a feasibility study on ammonia co-fired thermal power, overseen by NEDO. The project aims to develop ammonia combustion that does not emit CO_2, as well as address cost challenges along the supply chain.[144] Japan's Ministry of the Environment has awarded funding to Japanese consulting firm, Nippon Engineering Consultants; Queensland utility company, CS Energy; and Japanese trading house, Sojitz. The joint project will involve producing hydrogen from solar power in Queensland, before transporting it to Palau where it will be used in small fuel cells. The project currently has a scheduled completion date in March 2024 to produce hydrogen from renewables in countries with abundant resources and transport it for use in other regions.[145] Japanese companies have a number of gas and coal assets (thermal and metallurgical) located in Australia (WA, QLD, NSW), and are exploring opportunities to produce hydrogen from these. JOGMEC and Mitsui E&P Australia Pty Ltd started Joint Feasibility Study on CCS for creation of a supply chain of low carbon ammonia in Western Australia.[146] JERA and Yara International concluded an MOU related to cooperation in the ammonia value chain business, including development of a blue ammonia production plant.[147]

[139] Kawasaki (2019) World's First Liquefied Hydrogen Carrier SUISO FRONTIER Launches Building an International Hydrogen Energy Supply Chain Aimed at Carbon-free Society. https://global.kawasaki.com/en/corp/newsroom/news/detail/?f=20191211_3487&wovn=it; HESC (2022) The Suiso Frontier Departs Australia for Japan

[140] Nagashima M (2020) Japan's Hydrogen Society Ambition: 2020 Status and Perspectives. IFRI https://www.ifri.org/sites/default/files/atoms/files/nagashima_japan_hydrogen_2020.pdf

[141] JTXG Nippon Oil & Energy, Chiyoda Corporation, the University of Tokyo and University of Queensland (2019) Succeeded in the world's first technical verification to produce "CO2-free hydrogen" at low cost. Press Release. https://www.chiyodacorp.com/media/190315_e.pdf; Arias J (2019) Hydrogen and Fuel Cells in Japan. EU-Japan Centre for Industrial Cooperation https://www.eu-japan.eu/sites/default/files/publications/docs/hydrogen_and_fuel_cells_in_japan.pdf

[142] JOGMEC (2021) FY2021 Feasibility Study on Fuel Ammonia Value Chain from Australia to Japan Specification. http://www.jogmec.go.jp/english/bid/content/300372063.pdf

[143] Feasibility Study on Establishing a Clean Fuel Ammonia Supply Chain from Australia to Japan https://www.jogmec.go.jp/english/bid/content/300373304.pdf; https://www.jogmec.go.jp/english/news/release/news_15_000001_00022.html

[144] Nagashima M (2020) Japan's Hydrogen Society Ambition: 2020 Status and Perspectives. IFRI https://www.ifri.org/sites/default/files/atoms/files/nagashima_japan_hydrogen_2020.pdf

[145] Argus (2022) Japan's Sojitz to produce green hydrogen in Australia. https://www.argusmedia.com/en/news/2291286-japans-sojitz-to-produce-green-hydrogen-in-australia

[146]Commencement of Joint Feasibility Study on CCS for Creation of a Supply Chain of Low Carbon Ammonia in Western Australia https://www.jogmec.go.jp/english/news/release/news_15_000001_00026.html

[147] JERA and Yara International Conclude an MOU Related to Cooperation in the Ammonia Value Chain Business, Including Development of a Blue Ammonia Production Plant https://www.jera.co.jp/english/information/20210511_675

Country	Projects
Brunei	In June 2020, Japan and Brunei launched the world's first full scale supply chain demonstration project, the Hydrogen Supply Chain utilising the Organic Chemical Hydride Method.[148] The project was led by Japan's Advanced Hydrogen Energy Chain Association for Technology Development (AHEAD), a consortium of Chiyoda, Mitsubishi, Mitsui and NYK. [149] The pilot project produces MCH in Brunei produced via hydrogenation of toluene with hydrogen produced via steam reforming of a process gas from an LNG plant. The MCH is then shipped to Kawasaki City of Kanagawa Prefecture where hydrogen is extracted from the MCH at a local dehydrogenation plant. The hydrogen is utilised as fuel for the Keihin Refinery Thermal Power Plant (affiliate of TOA Oil Co Ltd).[150] Toluene is then shipped back to Brunei for re-hydrogenation in a circular loop.[151]
Norway	In 2016-2019 Japan and Norway completed the HYPER project, in an EUR 2 million collaboration between KHI, Mitsubishi Corporation, Nel, Shell and SINTEF Energy Research. Hydrogen was produced in Norway from natural gas with CCS, and from surplus wind and hydropower, and transported to Japan as liquid hydrogen. With the delivery at JPY 24 per Nm^3, this was cheaper than the hydrogen produced from the Australian coal-based project, and aligns with Japan's long-term priorities for climate-friendly production methods.[152]
New Zealand	After signing an MoC with New Zealand in 2018, the Obayashi Corporation and Tuaropaki Trust of New Zealand begun a joint R&D project on the construction of a 1.5 MW hydrogen plant that will produce 100 tonnes of hydrogen using Tuaropaki's geothermal resources. [153] The plant is planned to be operational by 2021.
UAE	Mitsui & Co., Ltd participated in Low-carbon Ammonia Production Project in Abu Dhabi, UAE.[154]
Indonesia	In June 2022 MHI commenced feasibility studies on the use of ammonia for power generation in Indonesia.[155]
Malaysia	In October 2021 IHI and Partners launched ammonia co-firing technology feasibility assessments at coal power stations in Malaysia with partners and for other companies to establish local carbon-free Ammonia Supply Chain.[156]

[148] Takeo Kumagai (2020) AHEAD launches Brunei-Japan hydrogen supply chain for power generation in Tokyo Bay. S&P Global Platts https://www.spglobal.com/platts/en/market-insights/latest-news/natural-gas/062520-ahead-launches-brunei-japan-hydrogen-supply-chain-for-power-generation-in-tokyo-bay

[149] NEDO (2017) NEDO to start a full-scale demonstration project on the world's first global hydrogen supply chain. News. https://www.nedo.go.jp/english/news/AA5en_100278.html; http://www.env.go.jp/earth/ccu/Keynote%203.pdf

[150] Arias J (2019) Hydrogen and Fuel Cells in Japan. EU-Japan Centre for Industrial Cooperation https://www.eu-japan.eu/sites/default/files/publications/docs/hydrogen_and_fuel_cells_in_japan.pdf; Kumagai T (2020) AHEAD launches Brunei-Japan hydrogen supply chain for power generation in Tokyo Bay. S&P Global Platts https://www.spglobal.com/platts/en/market-insights/latest-news/natural-gas/062520-ahead-launches-brunei-japan-hydrogen-supply-chain-for-power-generation-in-tokyo-bay

[151] Nagashima M (2020) Japan's Hydrogen Society Ambition: 2020 Status and Perspectives. IFRI https://www.ifri.org/sites/default/files/atoms/files/nagashima_japan_hydrogen_2020.pdf

[152] Arias J (2019) Hydrogen and Fuel Cells in Japan. EU-Japan Centre for Industrial Cooperation https://www.eu-japan.eu/sites/default/files/publications/docs/hydrogen_and_fuel_cells_in_japan.pdf

[153] Nagashima M (2020) Japan's Hydrogen Society Ambition: 2020 Status and Perspectives. IFRI https://www.ifri.org/sites/default/files/atoms/files/nagashima_japan_hydrogen_2020.pdf

[154] Mitsui to Participate in Low-carbon Ammonia Production Project in Abu Dhabi https://www.mitsui.com/jp/en/topics/2022/1243562_13410.html

[155] MHI Commences Feasibility Studies on Use of Ammonia for Power Generation in Indonesia https://power.mhi.com/news/20220607.html

[156] IHI and Partners Launching Ammonia Co-Firing Technology Feasibility Assessments https://www.ihi.co.jp/en/all_news/2021/resources_energy_environment/1197552_3360.html

Country	Projects
India	In March 2022, IHI commenced the technical and economic feasibility study in order to achieve ammonia co-firing at a coal fired power plant in India. [157]
Canada	In May 2022, ITOCHU announced project to manufacture and sell blue ammonia and blue methanol in Canada.[158]

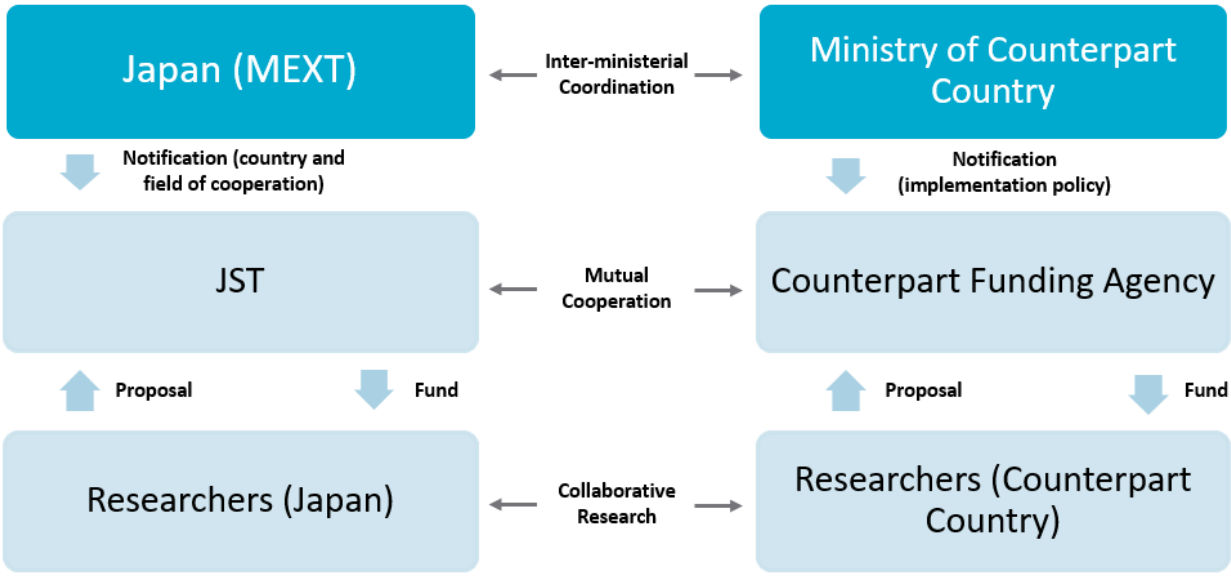
Strategic International Collaborative Research Program (SICORP)

The JST has been funding and executing the international joint research programme called SICORP since 2009, with leading countries and regions in research fields strategically prioritised by the MEXT. Several international joint projects in hydrogen have been conducted recently, are currently ongoing, or have received a call for proposals (summarised in *Table 12: JST (SICORP) International joint projects in hydrogen*).

The collaboration structure of SICORP, shown in Figure 6, is three-tiered such that there is:

1. Inter-ministerial engagement and coordination between MEXT and counterpart country ministry.
2. Mutual cooperation and joint funding between JST and counterpart country funding agency.
3. Collaborative research engagement between researchers from Japan and counterpart country.

Figure 6: SICORP collaboration structure



Adapted from: JST (2021) Overview of SICORP <https://www.jst.go.jp/inter/english/program_e/structure_e/general.html>

[157] Commencement of Technical and Economic Feasibility Study in order to Achieve Ammonia Co-Firing
https://www.ihi.co.jp/en/all_news/2021/resources_energy_environment/1197687_3360.html

[158] ITOCHU Announces Project to Manufacture and Sell Blue Ammonia and Blue Methanol
https://www.itochu.co.jp/en/news/press/2022/220524.html

Table 12: JST (SICORP) International joint projects in hydrogen[159]

Country	Relationship	Project	Status
Germany	Bilateral	Joint call for "Hydrogen Technologies", efficient and sustainable materials for hydrogen technologies, and sustainable propulsion for maritime transport based on hydrogen production from renewable energy. All participating institutions in Germany in Japan	Call for proposals, June 2021
Australia	Bilateral	Australia had a bilateral relationship with SICP undertaking marine research, but not in hydrogen. Australia through the NHMRC is also part of the e-ASIA JRP multilateral collaboration group under SICORP. Relevant fields of cooperation in the e-ASIA JRP group include alternative energy, however the NHMRC does not participate in the alternative energy field.	
EU	Bilateral	Selective CO_2 conversion in renewable methanol through innovative heterogeneous catalyst systems optimized for advanced hydrogenation technologies (LAURELIN) Tokyo Institute of Technology and Instituto de Tecnología Química (ITQ UPV-CSIC), Spain	Ongoing, 2021-2023
EU	Bilateral	Air Carbon Recycling for Aviation Fuel Technology (4AirCRAFT) Hokkaido University and Foundation for the Development of New Hydrogen Technologies, Aragon, Spain	Ongoing, 2021-2023
EU	Multilateral (EIG concert-Japan)	Sustainable hydrogen technology as affordable and clean energy All participating institutions in EIG Concert-Japan	Call for Proposals, July 2021
EU	Bilateral	Novel routes and catalysts for synthesis of ammonia as alternative renewable fuel (ORACLE) Osaka Research Institute of Industrial Science and Technology, Aarhus University	Ongoing, 2021-2023
EU	Multilateral (EIG concert-Japan)	Development of advanced and innovative metal support cells using proton conducting ceramics to foster hydrogen society implementation (DAICHI) Kyushu University, Oslo University	Ongoing, 2018-2021
Switzerland	Bilateral	Research on hydrogen as a renewable energy carrier Kyushu University, Paul Scherrer Institute	Ongoing, 2019-2021

[159] SICORP (2021) Overview of SICORP. Japan Science and Technology Agency (JST) https://www.jst.go.jp/inter/english/program_e/structure_e/general.html

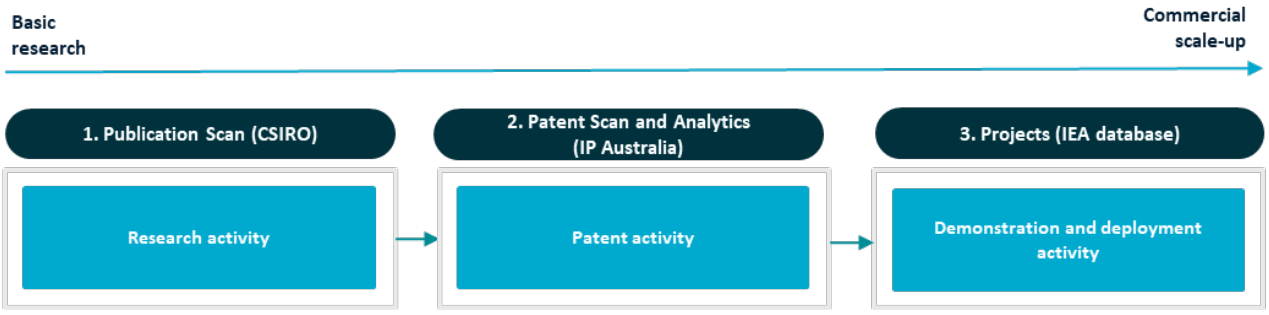
Country	Relationship	Project	Status
Switzerland	Bilateral	Development of new hydrogen storage alloys for utilisation of renewable energy and construction of the design guidelines aimed at practical use Shibaura Institute of Technology, Swiss Federal Institute of Technology in Lausanne (EPFL)	Ongoing, 2019-2021
Switzerland	Bilateral	Hydrogen fuel generation via photoelectrochemical and photovoltaic driven water splitting University of Tokyo, Laboratoire de photonique et interfaces, Swiss Federal Institute of Technology in Lausanne (EPFL)	Ongoing, 2019-2021
China	CHIRP (international collaboration hub)	Development of durable ion conductive membranes designed for high performance fuel cells University of Yamanashi, Sun Yat-sen University	Ongoing, 2019-2021
China	Bilateral	Efficient utilisation of heat and electric power from renewable energy in urban areas mediated by hydrogen energy Kyushu University, Dalian Institute of Chemical Physics, Dalian National Laboratory for Clean Energy, Chinese Academy of Science	Completed, 2018
China	Bilateral	Study of water management and low temperature start-up of fuel cell stack in bus application Hokkaido University, Tsinghua University	Completed, 2018
France	Bilateral	Molecular photocathodes for CO_2 reduction and hydrogen evolution (PhotoCAT) Tokyo Institute of Technology, CEA Grenoble	Completed 2017

1.6 Data insights: Japan's hydrogen RD&D activity

The following section provides data-driven insights on Japan's RD&D activity in hydrogen technologies. Research publication data, patent data, and commercial project data has been used to understand hydrogen related activity. While limitations exist with such an approach, these data sources do provide an opportunity to consider activity across the innovation spectrum from basic research to demonstration. It also aims to help identify technology areas that have received significant focus in each country and key organisations to support international collaboration efforts.

The data for this section was sourced from CSIRO's publications team, CSIRO's IP team, IP Australia, and the IEA's hydrogen projects database.

Figure 7: Hydrogen innovation activity data



1.6.1 Research publication data

Research publications in hydrogen are an indicator of basic and applied research activity. CSIRO's publications team has conducted a research publication scan to identify Japanese organisations conducting research across the hydrogen value chain. The publications search approach was developed in 2019 to support the report *Hydrogen Research, Development and Demonstration: Priorities and opportunities for Australia*. This search approach was applied in 2021 to provide an updated dataset for this report. The details of the search approach can be found in the *National Hydrogen Research, Development and Demonstration (RD&D): Technical Repository*.[160]

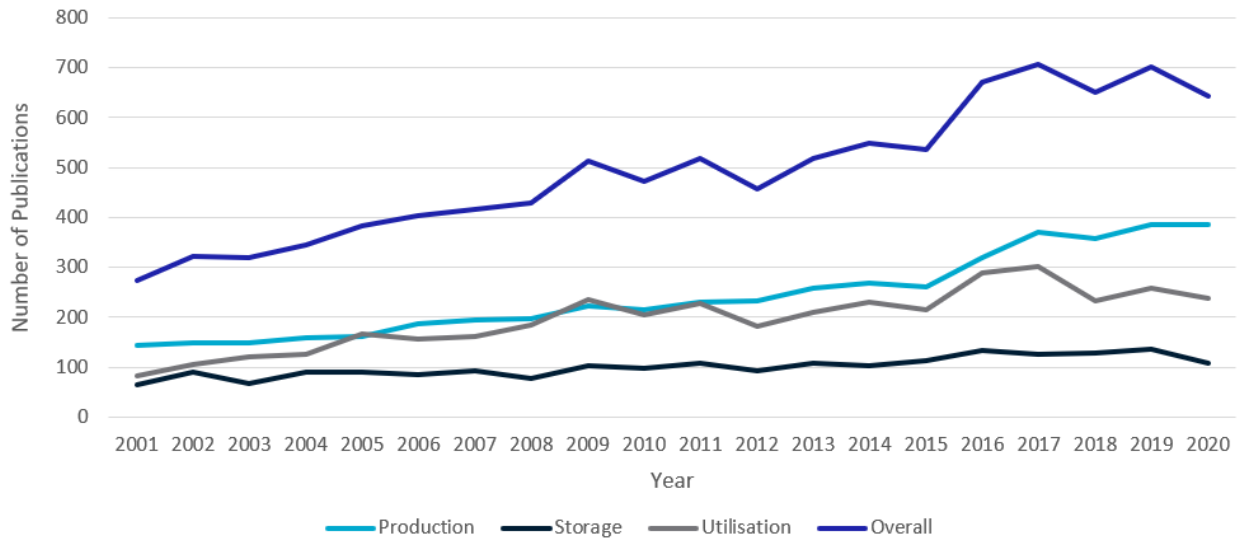
Figure 8 shows Japanese institutions ranked in terms of publication output across hydrogen production, storage and distribution, and utilisation from 2016-2020. Figure 9 shows Japan's country-wide research publication output trends across the hydrogen value chain.

[160] CSIRO (2019) National Hydrogen Research, Development and Demonstration (RD&D): Technical Repository. Available at https://www.csiro.au/en/work-with-us/services/consultancy-strategic-advice-services/csiro-futures/futures-reports/hydrogen-research

Figure 8: Top institutions by publication output (2016-2020)

Domestic Ranking	Production	Storage and distribution	Utilisation	Overall
	5th Globally	*4th Globally*	*3rd Globally*	*5th Globally*
1st	University of Tokyo	Kyushu University	Kyoto University	Kyushu University
2nd	Tohoku University	Kyoto University	Kyushu University	Kyoto University
3rd	Tokyo Institute of Technology	National Institute AIST	National Institute AIST	University of Tokyo
4th	Kyoto University	Hiroshima University	Japan Science & Technology Agency (JST)	National Institute AIST
5th	Kyushu University	Tohoku University	Tokyo Institute of Technology	Tohoku University

Figure 9: Japan's hydrogen-related research publication output (2001-2020)



1.6.2 Patent data

Patent activity in hydrogen is an indicator of applied R&D and innovation occurring across the value chain. This section draws on two different patent analytics approaches. CSIRO developed a search approach in 2019 to support the *Hydrogen Research, Development and Demonstration: Priorities and opportunities for Australia* report. CSIRO applied this approach to provide a patent landscape across the hydrogen value chain for each country. The details of the search approach and any limitations can be found in the *National Hydrogen Research, Development and Demonstration (RD&D): Technical Repository*.[161] The second approach, performed by IP Australia, builds on the hydrogen technology taxonomy developed in CSIRO's 2019 report to provide information on specific hydrogen technologies that sit within production, storage and utilisation. The full data visualisations, details of the search approach and any limitations can be found at *Patent analytics of hydrogen technologies: an interactive visualisation.*[162]

[161] CSIRO (2019) National Hydrogen Research, Development and Demonstration (RD&D): Technical Repository. Available at https://www.csiro.au/en/work-with-us/services/consultancy-strategic-advice-services/csiro-futures/futures-reports/hydrogen-research

[162] IP Australia (2021) Patent Analytics on Hydrogen Technology, Australian Government. Available at https://www.ipaustralia.gov.au/tools-resources/publications-reports/patent-analytics-hydrogen-technology

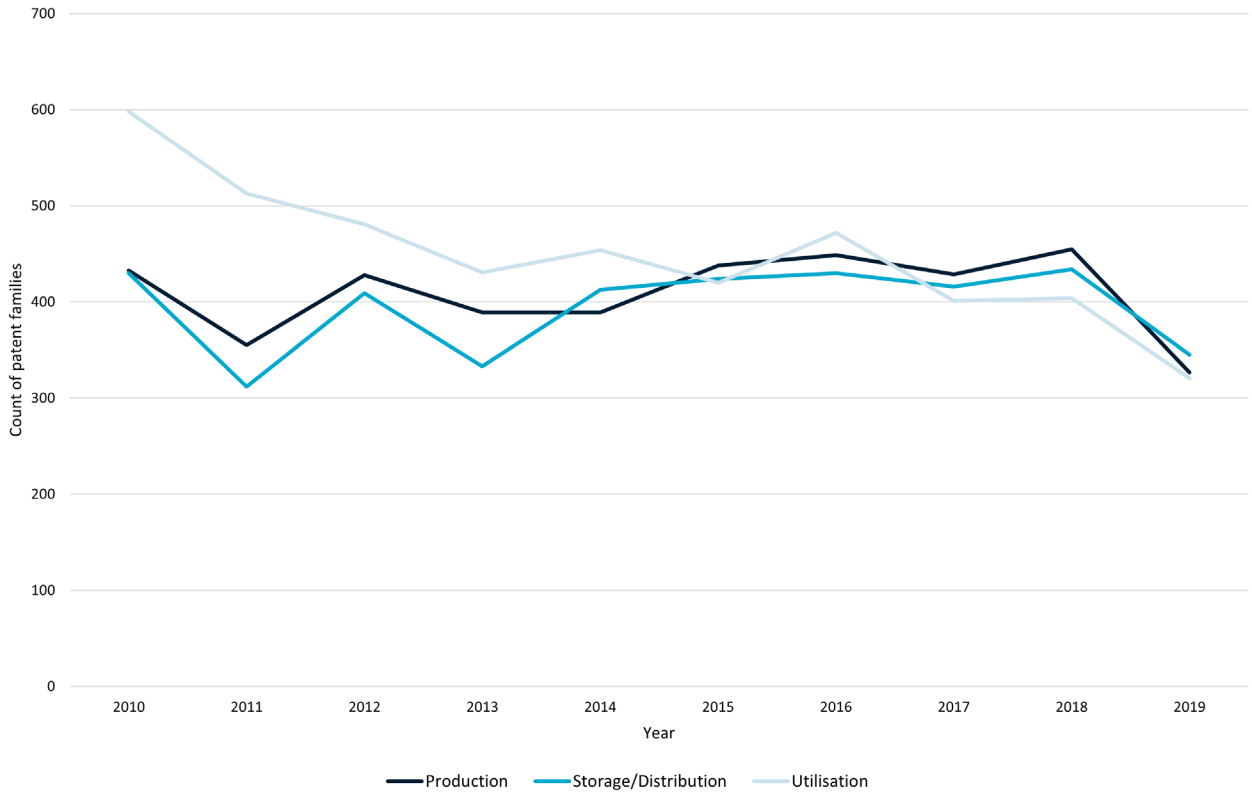
It should be noted that analysis of patent data is not necessarily representative of patent impact. As such, this data should be viewed holistically with the other data presented in this section, particularly project deployment.

Patent landscape of hydrogen value chain

Performed by the CSIRO, this patent landscape analyses patent family[163] filings across the hydrogen value chain. Figure 10 outlines patent filings over time across the areas of hydrogen production, storage/distribution and utilisation. Figure 11 shows the jurisdictions in which Japanese patent applicants are filing patents, outside of Japan. This provides an indication of which global markets, or manufacturing/commercialisation destinations are of interest to Japanese patent applicants or inventors.

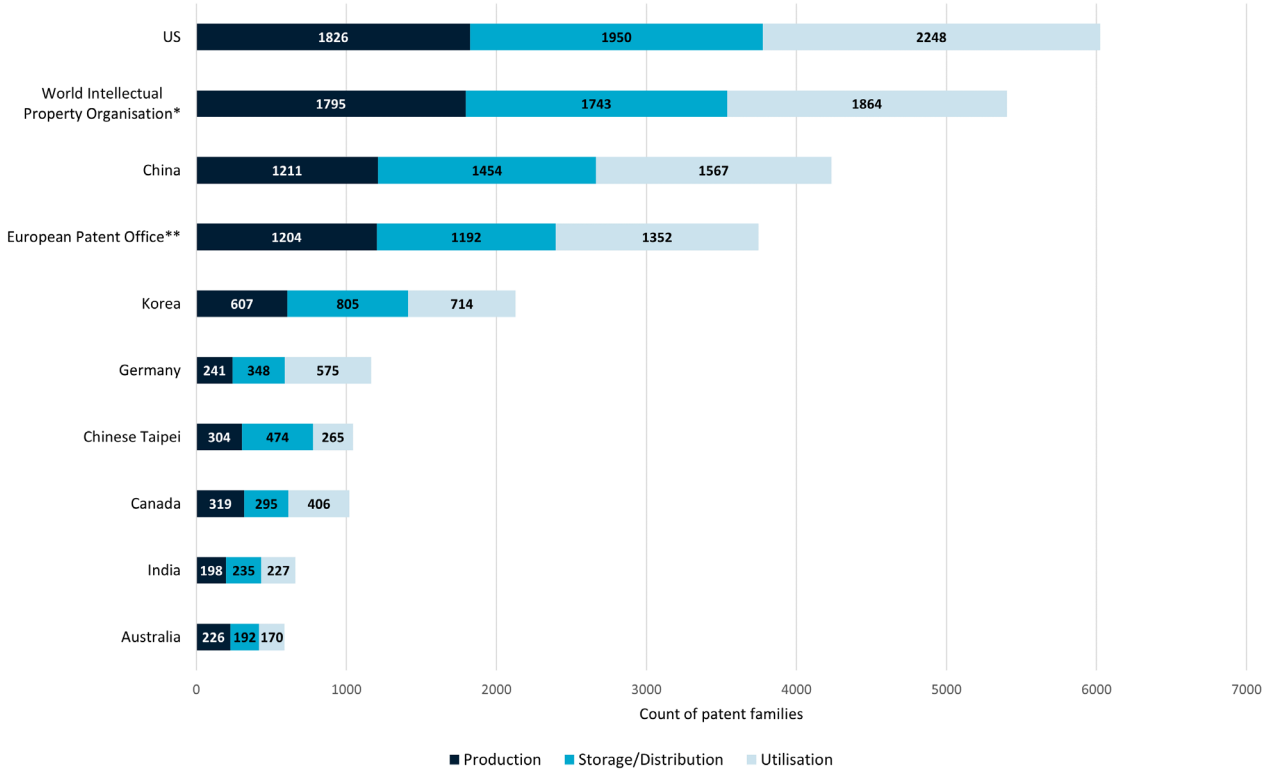
Note that patent databases have a delay of roughly 18 months, therefore 2020 and 2021 have been omitted from the graphs below. Some patent filings may also be counted twice as the categories of production, storage and utilisation may not be mutually exclusive in all instances and some could relate to multiple areas of the hydrogen value chain.

Figure 10: Patent filings over time across production, storage/distribution and utilisation



[163] Applications with the same priority, but filed in different jurisdictions, are known as patent families. Patent families enable us to analyse inventive activity regardless of the number of countries in which protection is sought. Patent families are used in analytics to represent a single invention.

Figure 11: Location of patent filings by Japanese patent applicants



*** The World Intellectual Property Organisation (WIPO) is an international organisation that promotes the protection of intellectual property and supervises administrative cooperation amongst the intellectual unions regarding protection of intellectual property. Patents filed in the WIPO enable applicants to obtain protection for their inventions in up to 153 of the parties to the Patent Cooperation Treaty.**

**** The European Patent Office enables investors, researchers and companies to obtain protection for their inventions in up to 44 countries, including all 27 EU member states.**

Patent analytics of specific hydrogen technologies

Data extracted from IP Australia's interactive visualisation provides an in-depth analysis of specific hydrogen technology developments. Figure 12 shows the number of patent families filed since 2010 for specific technology areas by Japanese applicants.

Table 13 shows the number of patent families filed by Japanese applicants since 2010 by sub-technology area, expressed as a percentage of total global patent family filings. Table 13 also shows the top organisations in Japan filing patents in each technology area. It should be noted that the majority of fuel cell technologies are categorised under the 'electricity generation' category.

Figure 12: Japan's patent family output by sub-technology area (2010-2020)

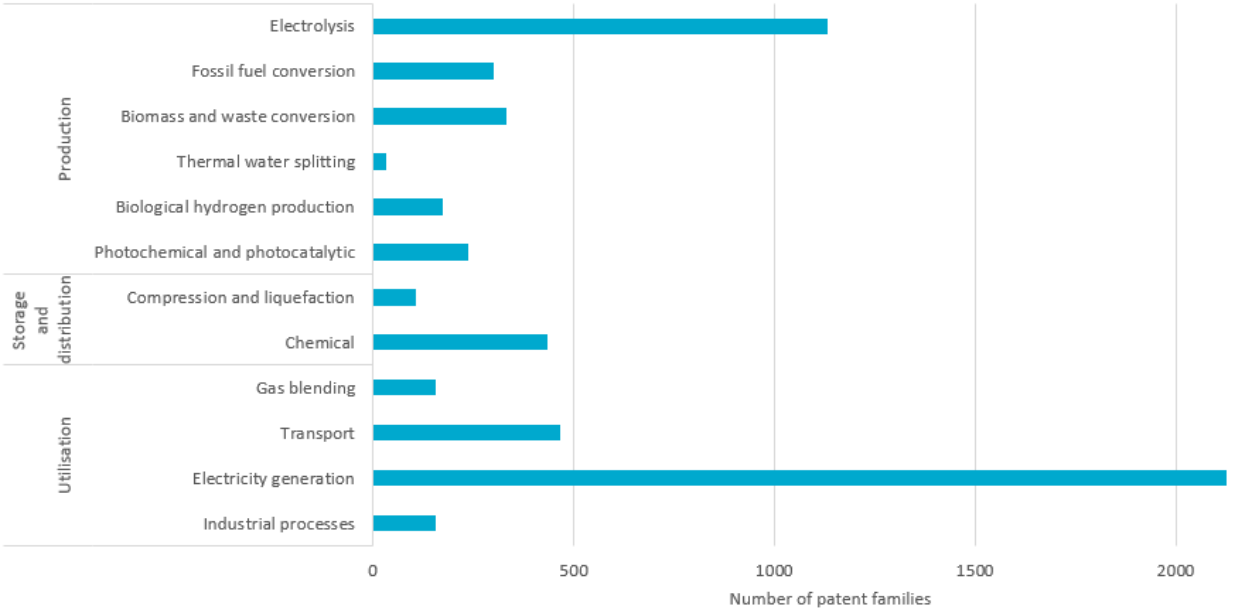


Table 13: Japan's IP output (number of patent families filed by Japanese applicants) by sub-technology area from 2010-2020

Technology area		IP output (% of global)	Leading companies	Leading non-profits and universities
Production	Electrolysis	14.1%	Panasonic, Toshiba, Honda Motor, Hitachi, Nippon Torimu	University of Tokyo, AIST, Yokohama National University
	Fossil fuel conversion	4.9%	Eneos, Mitsubishi Heavy Industries, Chiyoda Corporation, IHI, Cosmo Oil	JOGMEC, AIST, Tokyo Institute of Technology
	Biomass and waste conversion	11.2%	Eneos, Hitachi, Fuji Electric, Chiyoda Corporation	AIST, Kitami Institute of Technology, Kwansei Gakuin University
	Biological	7.2%	MIZ, Toyobo, Mizu, Sumimoto Chemical, Ajinomoto	Kumamoto University, Nagaoka University of Technology, Shinshu University
	Photochemical and photocatalytic	12.3%	Panasonic, Japan ARPChem, Fujifilm, Mitsubishi Chemical, Toshiba, Toyota Motor	University of Tokyo, AIST, Kyoto University, Nagoya Institute of Technology, Tokyo University of Science
	Thermal water splitting	4.7%	Toyota Motor, Mitsubishi Chemical, Panasonic, Mitsubishi Chemical	University of Tokyo, AIST, Japan Technological Research Association of Artificial Photosynthetic Chemical Process

Technology area		IP output (% of global)	Leading companies	Leading non-profits and universities
Storage and distribution	Compression and liquefaction	14.7%	Toyota Motor, Honda Motor, Panasonic, Kawasaki Heavy Industry, Nissan Motor	University of Yamanashi
	Chemical storage	17.5%	Tokyo Electron Ltd, Toyota Motor, Panasonic, Kao Corporation, Hitachi, Toshiba	Hokkaido University, Hiroshima University, Kyoto University, Tokyo Institute of Technology
Utilisation	Gas blending	11%	FujiFilm, Panasonic, Eneos, Toray, Sumimoto Chemical	Hiroshima University, AIST, Gifu University
	Transport	18.4%	Toyota Motor, Hitachi, Mazda Motor, Honda Motor, Eneos	AIST, Kyoto University, Japan Petroleum Energy Center
	Electricity generation	50.7%	Toto Ltd, NGK, Osaka Gas, Panasonic, Kyocera Corporation	Kyushu University, AIST, National Institute for Materials Science
	Industrial processes	3.6%	JFE Steel, Nippon Steel & Sumimoto Metal, Daicel Corporation, Bridgestone, JSR	AIST, Central Research Institute of Electric Power Industry, High Pressure Gas Safety Institute of Japan

IP Australia patent analytics on hydrogen technology

IP Australia has developed an interactive visualisation tool to provide hydrogen insights to researchers, academics, business and policy sectors. For more hydrogen IP statistics including key destination markets, origin profiles, applicant profiles, collaborations and specific patent searches, refer to IP Australia's Hydrogen Patent Landscape tool:

- https://www.ipaustralia.gov.au/tools-resources/publications-reports/patent-analytics-hydrogen-technology

1.6.3 Project data

Data from the IEA Hydrogen Projects Database (as at October 2021)[164] provides insight on clean hydrogen technology value chains deployed at pilot and commercial scale across Japan. Note that the following limitations should be taken into account:

- The database does not indicate whether the technologies used are indigenous or purchased from an overseas provider. While many countries often deploy their own technologies at scale, many countries purchase technologies from overseas to deploy locally. As such the database indicates deployment activity, but not necessarily the ability to translate indigenous R&D into commercial scale-up.
- This dataset counts only low-carbon hydrogen projects and their associated value chains. As such hydrogen production projects from gas, coal and oil without CCS are not included. Similarly, utilisation projects not related to a clean hydrogen project source are not included.
- The dataset reflects only projects occurring domestically, and therefore does not count projects undertaken by Japanese companies outside of Japan. As such, the table may understate Japan's activity, particularly its contribution to international supply chain development. This data should therefore be considered holistically with the rest of this report.
- Any limitations stated in the data collection methodology, definitions and assumptions should be taken into account (see IEA Hydrogen Projects Database for details).

For the purposes of this report, the dataset has been filtered to include only projects from 2010 through to projects expected to be operational by 2030, as this timespan best reflects current activities. Projects without a specified date have been excluded from the table below. Further, only projects that are at feasibility study stage, final investment decision, demonstration, and operational are included. Projects at the 'concept' stage are not included. It should be noted that the majority of projects listed span production, storage and multiple end-uses, and as such can be counted in more than one technology category.

Table 14: Japan's domestic clean hydrogen project data

Technology	Sub-technology		Domestic project count	% of global
Production	Electrolysis	PEM	17	9.2
		Alkaline	2	1.7
		SOE	-	-
		Other or unspecified	5	2.0
	Fossil fuel conversion	Coal gasification with CCS	-	-
		Natural gas with CCS	1	2.8
		Oil with CCS	-	-
		Methane pyrolysis	-	-

[164] IEA (2021) Hydrogen Projects Database. Available at https://www.iea.org/data-and-statistics/data-product/hydrogen-projects-database

Technology	Sub-technology		Domestic project count	% of global
	Biomass and waste conversion		1	6.7
	Photochemical and photocatalytic		-	-
	Biological production		-	-
	Thermal water splitting		-	-
Storage and distribution	Compression and liquefaction		24	4.7
	Chemical carriers	Ammonia	-	-
		Methane	1	1.9
		Methanol	-	-
		Synfuels	-	-
Utilisation	Gas blending		-	-
	Transport		12	5.1
	Electricity generation		15	11.2
	Industrial processes	Refining	-	-
		Ammonia	-	-
		Methane	-	-
		Iron and steel	1	4.8
		Biofuels	-	-
		Synfuel	-	-
		Other industry	1	0.7

IEA Hydrogen Projects Database

The latest version of the IEA Hydrogen Projects Database can be found at:

- https://www.iea.org/data-and-statistics/data-product/hydrogen-projects-database

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