Hydrogen Factsheet - Japan

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Political and economic environment	
Main export partners	Top 5 in 2020: • China (24%) • US (20%) • South Korea (7.5%) • Hong Kong (5.4%) • Thailand (4.3%) Top 3 EU export partners in 2020: • Germany (2.9%) • Netherlands (1.8%) • Belgium (1.1%) (TRADING ECONOMICS 2021)
Main export goods	Top 5 in 2020: • Vehicles other than railway, tramway (19%) • Machinery, nuclear reactors, boilers (19%) • Electrical, electronic equipment (16%) • Commodities not specified according to kind (6.4%) • Optical, photo, technical, medical apparatus (5.8%) (TRADING ECONOMICS 2021)
Trade agreements with	• Singapore, Mexico, Malaysia, Chile, Thailand, Indonesia, Brunei, Philippines, Switzerland, Vietnam, India, Peru, Australia, Mongolia (EPA) • ASEAN- Japan Comprehensive (EPA) • Trans-Pacific Partnership Agreement (TPP12) • Comprehensive and Progressive Agreement for Trans-Pacific Partnership (TPP11) • Japan-EU Economic Partnership Agreement • Japan-US Trade Agreement and Japan-US Digital Trade Agreement • Japan-UK Comprehensive EPA • Regional Comprehensive Economic Partnership (RCEP) Agreement (Ministry of Foreign Affairs of Japan 2020)
Hydrogen strategy and economy	
Existing hydrogen strategy	• Released in December 2017 (METI 2017) • Focus on hydrogen imports (fossil and renewable) due to lack of domestic resources • Expected demand (according to green growth strategy): 3 Mt by 2030, 20 Mt by 2050 • Hydrogen application expected in power generation, transport, heating and industry • Strong focus on hydrogen technology development and export (e.g. fuel cells)
Projects in operation[1]	• 19x electrolysis plants (~12 MW, 3 green, 16 with grid/other electricity) • 1x from biomass gasification (269 nm^2 H_2/h)

[1] IEA Hydrogen Project Database

Planned hydrogen production projects [up to 2030] [2]	• 2x electrolysis plants (4.5 MW, 1 green, 1 with grid/other electricity)
Existing CCS projects for blue hydrogen	• The Global CCS Institute (Global CCS Institute 2021) lists six CCS projects in Japan, of which one was a hydrogen production project, the Tomakomai CCS Demonstration Project (ran from 2016 to 2019). • CCS is planned for the Japan-Australia blue hydrogen supply chain project “HySTRA” (hydrogen production from brown coal combined with CCS, but CCS is not yet implemented). • Focus on carbon recycling / CCU (due to limited domestic storage possibilities) (METI 2020). Furthermore, an export of carbon dioxide for storage is being discussed.
Support schemes or funding facilities for clean hydrogen	• There is one major NEDO funded green hydrogen project, the Fukushima Hydrogen Energy Research Field (FH2R), including a 20 MW solar PV plant and a 10 MW alkaline electrolyser. Additional projects are focused on blue as well as grey hydrogen, to be outfitted with CCS/CCU technology. • Funds amounting to 70 billion Yen (539 million EUR) are made available for R&D on the scaling and modularization of electrolysers, amongst others, following the vision to establish the foundation for green hydrogen production in Japan and reduce electrolyser costs up to about 1/6 of the current costs.
Potential branches for domestic hydrogen demand	• Transport (fuel cell passenger vehicles, busses, trucks, trains, ships, aviation) • Stationary fuel cells • Power generation • Industry decarbonization (especially steel and chemical industries)
Exporting potential in strategy [TWh per year]	• Japan will be a net importer of hydrogen and exporter of hydrogen-related technology.
Main hydrogen production technology in focus	• Both blue and green hydrogen
Primary focus of export substance	• Japan will be a net importer and is thus seeking to expand the hydrogen supply network by building government-level relationships with resource-rich countries. At the same time, Japan seeks to strengthen its role as a technology exporter in the field of hydrogen.

Estimated costs of hydrogen production [LCOH in USD/kg] [3]	Year	2020	2030	2040	2050
	baseline	7.0 - 7.1	4.9 - 5.5	3.9 - 4.7	3.1 - 4.2
	optimistic	5.4 - 5.9	3.7 - 4.8	2.7 - 3.9	1.9 - 3.3
	Goals according to Green Growth Strategy		3		<2

Transportation to Europe in hydrogen strategy	• No transportation to Europe is planned. Japan will depend on hydrogen imports itself and is heavily engaged in expanding its international cooperation to foster the respective supply chain development. Main strategies currently focus on shipping of hydrogen and derivates.

[2] IEA Hydrogen Project Database
[3] Data based on Brändle et. al. 2020 (EWI H2-Tool): low temperature electrolysis.

Main sustainability challenges		
Water conflicts	• Even though Japan had water issues in the past, with a large part of the population being affected by a substantial drought during the dry summer of 1994, water scarcity and conflicts are no issue for the foreseeable future.	
Land conflicts	• There are land conflicts associated with renewable energy expansion such as solar PV and onshore wind which mainly originate from a lack of social acceptance at the local level. They centre around issues such as landscape changes, risks of landslides and competition for use between agriculture and the energy industry (Akita et al 2020,17).	
Energy poverty	• Share of population with access to electricity: 100% (World Bank 2019). Yet, there are a few cases of energy poverty, with an increase being observed since the 2000s (Okushima 2017).	
Monitoring for natural gas and CCS	• Potential natural gas sources are being looked into and there was a discovery of natural gas in 2019. However, both the supply of natural gas as well as the storage potential for CCS are greatly limited due to geological conditions.	
Existing future energy system & decarbonisation strategy	2018	2030
Total gross electricity production (net imports) [TWh]	1,051.2 (0) (Renewable Energy Institute 2020)	1,070 (0) (Renewable Energy Institute 2020)
RES share in electricity generation[4] [%]	17%	36-38%
CO_2 intensity of electricity generation [gCO_2/kWh, 2018]	428	367
Largest fossil fuel-based electricity generation (share in total generation)]	38% share of natural gas	20% share of natural gas (The Japan Times 2021) (Reuters 2021)
CO_2 emissions from electricity production (from other energy industry own use, manufacturing industries and construction) [$MtCO_2$, 2018]	450 $MtCO_2$ (METI 2020)	360 $MtCO_2$ (METI 2020)
Goals decarbonisation for 2050 (NDC discussion)	• Net-zero goal for 2050	

[4] IRENA (2020): Renewable Energy Statistics

Opportunities for cooperation and trade on hydrogen between Japan and the EU

Strengths	Weaknesses
Pre-existent trade, industry and research cooperation among EU and Japan.	The strategies of Japan and the EU differ in some respects, e.g. regarding the strong Japanese focus on hydrogen cars, power generation turbines and fuel cells (METI 2021).
Both Japan and EU countries are at the forefront of hydrogen-related technologies, however partly in different fields. This opens opportunities for collaboration.	In some areas, Japan and the EU have competing hydrogen-related technology export interests.
Hydrogen imports are a joint challenge. Certification and rules for trade might be addressed jointly. Japan is part of the International Partnership for Hydrogen and Fuel Cells in the Economy (IPHE), Clean Energy Ministerial Hydrogen Initiative (CEM H2I), and Clean Hydrogen Mission (Mission Innovation).	Differing perspectives on certification and sustainability. Japan has a strong focus on blue hydrogen and CCS.

Convergence	Divergence
Joint climate neutrality goal by 2050.	Japan expects a larger role for fossil fuels in 2050, to be offset using negative emission technologies and international cooperation.
Blue hydrogen viewed as a transitory fuel.	The relative importance of green vs. blue hydrogen differs between the strategies of the EU and Japan.
Hydrogen import dependence and focus on supply chain development. International cooperation focused on standardisation, (international) regulation, and technological development.	Hydrogen for power generation is a strong focus in Japan at a comparatively early stage of the transition, which could lead to different import needs.

Executive Summary

Japan is leading on hydrogen, with a particular focus on its application in transport, heating and energy production. In many of these sectors, Japan is already a technological leader. The country furthermore aims to strengthen its leadership in these sectors through measures laid out in its hydrogen and green growth strategies.

At the same time, Japan is highly dependent on energy imports and has very few domestic energy resources, both fossil and renewable. However, it does possess large theoretical potential for floating offshore wind expansion, which the Japanese government aims to tap into in order to allow for an accelerated energy transition. Nevertheless, Japan will – as many EU member states – need to become a major importer of hydrogen to fuel its transition to net zero by 2050. The country has already started to establish international partnerships and is leading with regards to international supply chain development. Two hydrogen supply chain demonstration projects are already operational, one importing chemically transformed hydrogen from Brunei and one importing liquified hydrogen from Australia, using the world's first liquified hydrogen carrier.

Currently, both these international supply chain projects are focused on hydrogen production from fossil fuels – with CCS not yet being implemented. In the medium run, Japan however plans to rely heavily on CCS and CCU technologies for the decarbonization of its hydrogen production and economy. In the long run, green hydrogen is furthermore expected to play a major role and Japan is also investing in related demonstration projects, such as the Fukushima Hydrogen Energy Research Field, whose 10-MW electrolyser was the world's largest at the time of its opening in 2020.

Even though Japan and the EU are competing with regard to some hydrogen technologies and are currently pursuing different energy and climate policies with a differing emphasis on green hydrogen, Japan can be a crucial long-term partner for the EU. Japan is not only one of the leading countries on the development of hydrogen technologies, notably fuel cells, it will also face similar supply chain issues as the EU and also pursues a long-term net zero target, even though Japan focuses strongly on carbon capture and will, according to current plans, still use a non-marginal share of fossil fuels for electricity generation by 2050. Therefore, cooperation with Japan could be especially promising with regards to the ramp-up of an international hydrogen market, the establishment of international supply chains to third countries, which could supply both Japan and the EU, as well as to topics regarding certification and regulation of both hydrogen and related technologies.

1. Political system and economy

Japan is a constitutional monarchy, and the authority to pass legislation rests with the National Diet, consisting of two houses, the House of Representatives and the House of Councillors. (D'Ambrogio 2020). Most legislation is sponsored by the executive branch, namely the cabinet. The Prime Minister heads the cabinet and has the authority to appoint and dismiss other members as well as submit policy proposals to the cabinet on basic principles of security, financial management, economy, budget planning and administration (Pekkanen und Pekkanen 2021). Decision-making with regards to energy policy is, therefore, highly centralised within the cabinet office. The power to appoint the Prime Minister rests with the Diet. Elections occur in the lower house (House of Representatives) at a minimum of every four years, whilst in the upper house (House of Councillors) elections are held for half of the house every three years (Neely 2016). Japan is divided into 47 prefectures (D'Ambrogio 2020) which have a degree of authority over labour, education, social welfare and health policy. However, they depend on the central government for financial and administrative resources, and hence only have limited autonomy over decision-making.

The Liberal Democratic Party has been able to form majorities (outright or with coalitions) in both houses since 2012, and has hence been in government since then. The LDP has dominated Japanese politics since 1955 (IFES 2021). The LDP won the 2021 general election in October once again, securing enough seats to govern without a coalition partner.

Fumio Kishida, who succeeded Yoshihide Suga as prime minister after his resignation in September 2021, is generally considered to be open to renewable energies and the energy transition as a whole, and also sees a role for hydrogen and nuclear power. The new government will most likely not implement major changes to the current policy trajectory of a gradual energy transition with a clear focus on hydrogen application and an involvement of the business community. In addition, nuclear energy remains an important topic in Japan and while in particular the construction of new nuclear power plants remains an issue of debate, it is generally assumed that Japan will again expand its nuclear capacity going forward (The Japan Times 2021) (Nikkei 2021) (Reuters 2021).

With 5.06 trillion USD (World Bank Group 2021), Japan has the third highest nominal GDP worldwide, behind the US and China. Its GDP per capita in 2019 was 40,113 USD. Japan has a highly developed economy, and is among the most advanced producers of several industrial and technological goods, including motor vehicles, electronic equipment and chemicals. It expends many resources on R&D, with approximately 19.5 trillion Yen (EU-Japan Centre 2021b) being spent in 2018. In addition to its industrial sector, the services industry makes up the bulk of GDP and includes retail, banking, insurance and telecommunications.

International trade has long played an important role in the economy. Exports accounted for 18.5% of GDP in 2018, and its major export trading partners in 2020 were China (24%), the US (20%) and South Korea (7.5%) (TRADING ECONOMICS 2021). Meanwhile, a scarcity of natural resources and land area has contributed to Japan's reliance on imports. It's three largest import partners were China (23%), the United States (11%) and Australia (6%). Equally, in the last ten years Japan's government has entered into multiple trade agreements. In 2016 Japan ratified the Trans-Pacific Partnership (TTP), later modified after the US withdrawal to the Comprehensive and Progressive Agreement for Trans-Pacific Partnership (CPTPP). In 2017, the EU and Japan agreed to an Economic Partnership Agreement that came into force in 2019.

Since the 1990s, Japan's economy has remained on a trajectory of limited economic growth, due to in part structural issues of an ageing population and issues in the labour market. Despite some market reforms under the Abe Administration, the country still faces some challenges, including the ageing population, slowing birth rate and the public deficit (237.6% of GDP in 2017) (Central Intelligence Agency 2021). And while falling international and domestic demand at the onset of the Covid-19 pandemic left the economy vulnerable, a stimulus package of approximately USD 1 trillion was enacted to counteract these effects.

2. Energy and Electricity

2.1 Production and demand

Japan is heavily reliant on **imported fossil fuels**, even though the country actively seeks to reduce its import dependency and pursues an energy transition focused mostly on solar and – in the future – on offshore wind. In the fiscal year (FY) 2019, Japan's primary energy supply was composed of 37.2% oil, 25.4% coal, 22.4% natural gas, 3.5% hydro power, 5.8% non-hydro renewable energy, 3% energy from recovered waste heat and 2.8% nuclear power. Its dependency on fossil fuels thus amounted to 85% (METI 2021).

The **generation of electricity** follows a similar pattern, however with a continuously rising renewable share. In FY 2019, Japan generated 37.1% of its electricity from natural gas; 31.9% from coal; 18% from renewables (7.7% hydropower, 6.7% solar, 2.6% bioenergy, 0.7% wind, 0.3% geothermal), 6.8% from petroleum and waste, as well as 6.2% from nuclear (Renewable Energy Institute 2021). Excluding private power generation, for which data is not yet available, in FY 2020, the renewable energy share in electricity generation increased to 23% (REI 2021).

2.2 Import and export

Japan's high dependency on fossil fuels combined with the lack of significant domestic resources also explains Japan's relatively low energy self-sufficiency ratio, which only amounted to 11.8% in FY 2018, relating to the share of renewables and nuclear energy. The country therefore highly depends on energy imports, especially of oil, coal and natural gas (METI 2020). Australia is Japan's main supplier of LNG and coal, accounting for 40% and 68% of the imports in 2019, respectively (METI 2020). Countries in the Middle East act as main suppliers of oil to Japan (88% in 2019, whereby 35.8% came from Saudi Arabia and 29.7% from UAE) (METI 2020).

2.3 Forecasts

In July 2021, METI published a draft of the **revised *Basic Energy Plan*** (Sixth Basic or Strategic Energy Plan) which was approved by the Cabinet on October 22. Whereas the precedent plan envisioned a renewable share in electricity generation of 22-24%, the updated plan states that renewables should account for 36-38% of power supply by 2030, assigning a major role for solar and wind energy, with a share of 15% and 6%, respectively. The shares of coal, natural gas and oil in power supply are targeted to be 19%, 20% and 2%, respectively. New fuels like hydrogen and ammonia are planned to account for about 1% of the electricity mix in 2030. Nuclear power is projected to account for 20-22% of total power generation in 2030 (The Japan Times 2021) (Reuters 2021). Japan's ***Green Growth Strategy*** *Towards Carbon Neutrality 2050* published in December 2020 estimates an estimated increase in electricity demand of 30-50% and sets a scenario of 50-60% renewables in the electricity mix in 2050 as a point of reference.

3. Decarbonisation and RES policies

Due to its strong economy and manufacturing sector, Japan, which ranks third in nominal GDP, also ranked fifth in GHG emissions in 2017 (after China, USA, India and Russia in descending order), accounting for 3.4% of global emissions (METI 2020). GHG emissions increased after the Fukushima Earthquake in 2011 due to a shutdown of nuclear reactors, before falling again below pre-2011 levels in FY 2017. In FY 2018, Japan's emissions amounted to 1.24 billion tons, with 1.06 billion tons of CO_2 (METI 2020). In October 2020, Japan announced its **aim to reduce emissions to net zero by 2050**. The target was underlined in April 2021, when Prime Minister Yoshihide Suga announced an increase in the 2030 emission reduction target from 26% to 46% (vs. 2013). Additionally, further measures are scheduled to be taken in order to achieve a 50% reduction.

The government's net zero goal by 2050 has been enshrined in the ***Act on Promotion of Global Warming Countermeasures*** in May 2021. The law is intended to signal the Japanese government's determination at home and abroad, but above all to prevent the target from being revised in the event of a change of government. It obliges the government to establish a programme to combat global warming and to set clear targets for reducing GHG emissions. This obligation is delegated to local governments which are to formulate their own targets for the promotion of solar and wind energy and designate areas for renewable energy deployment. Facilitation of environmental impact assessments for renewables is to help drive the expansion (Kankyo 2021) (Prime Minister's Office of Japan 2021).

Due to its geography, Japan faces special challenges with respect to the expansion of renewables, with the mountainous terrain limiting the potential for onshore renewables. Having 6.7% of its electricity generated by solar, Japan already has the highest installed solar energy capacity per square metre of flat land. Additionally, due to the steeply sloping coastline, non-floating offshore wind turbines are almost exclusively feasible in low-lying marine areas. Therefore, Japan is increasingly looking into floating offshore wind as well as imports of green hydrogen. Additionally, the Japanese islands have differing grid infrastructure, some with very limited transmission capacity, limiting the electricity exchange.

Historically, the expansion of renewable energy in Japan was mainly driven by a feed-in tariff (FIT) (introduced in 2012) which replaced the previous renewable portfolio standard (RPS). From 2017, it has been complemented by an auction scheme for projects that exceed a certain size. As a result of the FIT, the share of renewables in electricity generation has grown at an average annual rate of 18% and to an overall share of 18% in FY 2019 (METI 2020). Solar accounts for the largest share of newly installed capacity under the FIT. In 2020, cumulative installed capacity was 67 GW for solar PV and 4 GW for wind (Renewable Energy Institute 2021). The competitiveness of renewable energy increased significantly: The cost of PV fell from 40 Yen/kWh (0.30 EUR/kWh) in 2012 to just 14 Yen/kWh (0.11 EUR/kWh) in 2019. In order to promote competition and reduce the burden on electricity consumers from the renewable energy levy, the Japanese parliament passed a bill in June 2020 to introduce a feed-in premium (FIP) system to substitute the FIT system (Nikkei 2020). This is, however, limited to the case of the "most marketable" energy technologies, e.g. for wind farms and large-scale PV plants, but excludes biomass, geothermal energy and small-scale PV plants (IRENA 2021). However, the design of the FIP system has yet to be defined. The revised *Renewable Energy Act* is scheduled to come into force on 1 April 2022.

Despite high potential, **offshore wind** has so far played a marginal role in electricity generation. Since 2019, however, new legislation has promoted offshore wind (*Act of Promoting Utilization of Sea Areas in Development of Power Generation Facilities Using Maritime Renewable Energy Resources*). The law states that sea areas that meet various requirements for offshore wind can be designated as support zones and used by operators for up to 30 years. In July 2019, eleven sea areas were selected as fundamentally suitable in a first stage, whereby four of them were classified as particularly suitable. The Green Growth Strategy, which was updated in June 2021, stipulates offshore wind targets of 10 GW and 30-45 GW by 2030 and 2040, respectively (METI 2021). In June 2021, the Ministry of Economy, Trade and Industry (METI) and the Ministry of Land, Infrastructure, Transport and Tourism (MLIT) published the results of the first public offshore wind tender. The project in Goto, Nagasaki Prefecture, was awarded to a consortium led by Toda Corporation, which submitted a project plan for the installation of eight turbines with a total capacity of 16.8 MW (METI 2021). In September 2021, METI and MLIT defined further sea areas off Happo Town and Noshiro City, both Akita Prefecture, as *Offshore Promotion Areas* (METI 2019).

The ***Green Growth Strategy Towards Carbon Neutrality 2050*** of the Japanese government (published in December 2020) represents the country's plan for reaching decarbonisation by 2050. It is "*an industrial policy which aims to create a positive cycle of economic growth and environmental protection*". It envisages the promotion of 14 growth sectors, whereby hydrogen and CCUS play a key role. The strategy stipulates decarbonisation of the electricity sector as well as the electrification of all sectors. Based on the estimation that electricity demand will increase by 30-50%, the strategy sets a scenario of 50-60% renewables in the electricity mix in 2050 as a point of reference. The remaining electricity is to come from hydrogen and ammonia power plants (10%), using hydrogen of a yet unspecified colour, as well as nuclear power and thermal power plants with CCUS (30-40%). As one of the appointed growth sectors, offshore wind is to be significantly expanded to 10 GW by 2030 and 30-45 GW by 2040 and costs are to drop to about 0.07 EUR/kWh by 2030-35 (METI 2021).

Two trillion Yen (approx. 15.3 billion EUR) of funding will be made available for the next ten years via the **Green Innovation Fund** to financially support R&D and deployment projects undertaken under the Green Growth Strategy, whereby NEDO is in charge of its operation. A budget of 300 billion Yen (2.3 billion EUR) is available for the demonstration of a large-scale hydrogen supply chain using liquefied hydrogen and/or methylcyclohexane (MCH) and large-scale hydrogen power generation systems. Moreover, a budget of 70 billion Yen (539 million EUR) is provided for R&D for electrolysers, the implementation of superior element technologies and the demonstration of decarbonization of basic chemicals and heat demand. The vision is to establish the foundation for green hydrogen production in Japan and reduce electrolyser costs down to about 1/6 of the current costs (METI 2021). Thereby, as well as by the provision of tax incentives, the strategy foresees the stimulation of significant private R&D and investment. Further, it stipulates the formulation of guidelines for transition finance and the creation of a scheme for long-term funds with an interest subsidy to attract global ESG investment, as well as regulatory reforms to promote the growth sectors. It also aims at increasing international cooperation with developed and emerging countries, especially with respect to innovation policy, joint projects (also in third countries) and in the field of standardisation and international regulation (METI 2021).

4. Hydrogen strategy and support schemes

Japan was the first country to formulate a hydrogen strategy, with its **Basic Hydrogen Strategy** published in December 2017. It was followed by the **Strategic Hydrogen and Fuel Cell Roadmap** and the **Hydrogen and Fuel Cells Technology Development Strategy**, adopted in March and September 2019, respectively (METI 2019). The country's aim to become a "hydrogen society" and to lead the global transition towards a hydrogen economy is driven by the expected potential of hydrogen with respect to decarbonisation, energy security and competitiveness (METI 2021). As outlined in the *Basic Hydrogen Strategy*, hydrogen is set to take a key role in the decarbonisation of power generation, as well as in transportation, heat use and industrial processes.

Further, hydrogen is expected to allow Japan to reduce and diversify its energy procurement and thus decrease the supply risks that it has historically faced as an energy resource scarce country. For Japan, hydrogen represents a means to achieve its "3E+S" goal, i.e. the best possible reconciliation of energy security, economic efficiency and environmental sustainability whilst ensuring safety (METI 2017).

Japan holds significant expertise in the field of **hydrogen-related technologies** and seeks to benefit from the opportunities associated with a major future global market which the Hydrogen Council estimated to amount to 2.5 trillion USD (approx. 2.1 trillion EUR) and to create 30 million jobs under the assumption of a 60%

emission mitigation scenario by 2050 (Hydrogen Strategy 2017, 16f). Japan aims to expand its role as an exporter of hydrogen-related products such as fuel cell vehicles (FCVs), hydrogen stations, stationary fuel cells (FC), CCS technology, hydrogen carrier ships and technologies, gas turbines and electrolysis systems (METI 2017).

At the same time, the country will depend on hydrogen imports from abroad, whereby the *Basic Hydrogen Strategy* stipulates both the import of green and blue hydrogen from countries that can provide it at low costs. Hydrogen transport is to be carried out in form of methylcyclohexane (MCH), ammonia or methane in addition to liquefied hydrogen. Whereas liquefied hydrogen and MCH only serve for transportation purposes, methane and ammonia will serve as both energy carrier and for direct usage. The usage of ammonia for gas turbines is envisioned for 2030 (METI 2017).

To simultaneously stimulate hydrogen imports and hydrogen-related technology exports, Japan aims to promote the establishment of international hydrogen supply chains covering the entire value chain from production over storage and transport to usage. A major challenge for the commercialisation of hydrogen technologies consists in their international standardisation (METI 2017, 36). To promote the global transition to a hydrogen economy, Japan proactively seeks to enhance international cooperation with both foreign governments and private companies, by making use of pre-existent institutions and initiatives such as IEA, Hydrogen Council, IPHE etc. (METI 2017). The *Basic Hydrogen Strategy* envisions to develop commercial scale supply chains by 2030, increase hydrogen demand in transport and introduce hydrogen for power generation (METI 2017, 20). With regard to hydrogen mobility, the strategy sees a role for hydrogen in cars, buses, forklifts, trucks and ships, ensuring maximal horizontal expansion of FC technologies and the effective usage of hydrogen station infrastructure (METI 2017, 29). With respect to the application of hydrogen for power generation, Japan aims to cut hydrogen power generation costs to 17 Yen/kWh (approx. 0.13 EUR/kWh) by around 2030. The long-term goal is to make it cost competitive with LNG power generation for which annual hydrogen procurement would need to increase to 5-10 million tons (METI 2017).

From 2030, both supply and demand are to be expanded further, including the application of hydrogen in industry. The aim is to achieve cost competitiveness with conventional energy sources (METI 2017, 20). Cost reductions are to be realised by reducing OPEX of renewable electricity and CAPEX of water electrolysis and other equipment, as well as by increasing the capacity utilization rate of hydrogen production equipment (METI 2017).

Hydrogen and related technologies are also at the centre of the ***Green Growth Strategy Towards Carbon Neutrality 2050*** (adopted in December 2020 and updated in June 2021). The strategy stipulates to reduce the cost of hydrogen to 3 USD/kg (2.59 EUR/kg) by 2030 and to less than 2 USD/kg (1.73 EUR/kg) by 2050. Hydrogen demand is expected to amount to 3 million tons by 2030 and approx. 20 million tons by 2050 (METI 2021).

The strategy seeks to support FCVs, FC trains and trucks, large-scale hydrogen power generation, hydrogen stations for FC trucks, R&D for zero-carbon steel and chemicals. To reduce the costs of hydrogen production, R&D is to be increased for the scaling and modularisation of electrolysers (PEM and AEM). Further, the strategy seeks to create regional models in the form of demonstration projects and to strengthen international cooperation, including with potential hydrogen suppliers (METI 2021).

5. Hydrogen sector in Japan

5.1 The status of Japan's hydrogen economy

Japan is committed to heavily expand the application of hydrogen in various sectors. Having been the first country to adopt a hydrogen strategy, Japan acts as a global forerunner. Transport applications stand out, with Japan focusing on FC passenger vehicles. Domestically, Japan supports FCV expansion with direct purchase subsidies and the roll-out of hydrogen stations. As of May 2021, Japan had constructed 162 hydrogen refuelling stations – the world's largest hydrogen station network – and has over 5,000 FCVs on the road. In addition to cars, Japan also supports FC buses, of which over 100 were in use by mid-2021, as well as the development of FC trains and trucks. Japan intends to expand the deployment of hydrogen cars and related technologies further, targeting 320 refuelling stations by 2025 and more than 400 by 2030. In addition, 800,000 FC cars are targeted for 2030.

Japan is also pursuing the development of commercial FC powered ships, which is targeted for 2030. NEDO has been promoting the development of a commercial FC vessel since 2020. The companies involved (ENEOS, Nippon Yusen, Toshiba, Kawasaki Heavy Industries und ClassNK) are developing a ship weighing ca. 150 tons with a capacity of around 100 people that can be operated with a 500kW hydrogen FC. In 2024, the demonstration operation is expected to start in the Yokohama Bay area (Toshiba 2020) (EU-Japan Centre 2020). Japanese companies also developed a passenger ferry with a capacity of 80 passengers, which has been operational since July 2021 (EU-Japan Centre 2021a).

In addition to hydrogen mobility, Japan also supports additional usage technologies, such as residential stationary FCs, of which 300,000 units have already been installed under the *Ene-Farm* initiative (Geitmann 2018). Until 2030, this number is targeted to increase to 5 million.

As stipulated in the *Basic Hydrogen Strategy*, another crucial application of hydrogen will be in power generation (METI 2017). In September 2021, the foundation stone of the first commercial hydrogen power plant in Japan was laid in Fujiyoshida, Yamanashi Prefecture, which is to meet the needs of about 100 households (Nikkei 2021). Furthermore, Japanese Mitsubishi Hitachi Power Systems has developed a gas turbine that can flexibly use hydrogen and natural gas (Kankyo 2020). At present, the operation of hydrogen power plants is not yet financially competitive. However, Japan hopes to be able to lower the price decisively by producing and importing larger quantities of hydrogen.

There are currently two government-supported hydrogen hubs, i.e. regional projects for the demonstration of hydrogen applications, the *Hydrogen Utilization Study Group in Chubu* that companies such as SMBC, Toyota, Air Liquide, Mitsubishi Chemical, Toho Gas, Eneos, idemitsu, Iwatani, a.o. form part of, as well as the *Hydrogen Utilization Council in Kobe* (Kansai area) that involve Iwatani, Marubeni, Kawasaki, Mitsubishi Power, J Power, Eneos, "K"LINE, Kobelco (Kobe Steel Group), Panasonic, Obayashi, a.o. (METI presentation SPIPA workshop 5/2021). It was also in Kobe, where Japan launched the world's first 100% hydrogen-fuelled heat and power generation system in an urban area in a test project in 2018 (NEDO 2020).

5.2 Relevant stakeholders, organisations and initiatives

Japan's **Ministry of Economy, Trade and Industry (METI)** is the ministry in charge of hydrogen-related issues. Following recent elections in Japan, Mr. Hagiuda Koichi was appointed Minister of Economy, Trade and Industry on October 4, 2021. Besides METI, the **New Energy and Industrial Technology Development Organization** (NEDO 2021) is the most relevant public stakeholder of the Japanese hydrogen ecosystem. NEDO describes itself as "*(…) a national research and development agency that creates innovation by promoting technological development necessary for realization of a sustainable society. NEDO acts as an innovation accelerator to contribute to the resolution of social issues by developing and demonstrating high-*

risk innovative technologies having practical application." With respect to hydrogen, NEDO is promoting technological development from production to transportation, storage, and the use of hydrogen, including FCs, hydrogen refuelling stations, hydrogen power generation, large-scale hydrogen supply chains, and power-to-gas technology. Within the organization's structure, the FC and Hydrogen Technology Office is part of NEDO's Smart Community and Energy Systems Department. NEDO's FY 2021 project list comprises four major hydrogen projects, mostly focused on hydrogen application, e.g. FCs and refuelling stations (NEDO 2021).

Japan is home to well established companies from the hydrogen sector, such as Panasonic (FCs), Toyota and Honda (FCVs), Mitsubishi Heavy Industries (e.g. hydrogen power generation technologies) or Asahi Kasei (electrolysers), amongst others.

In December 2020, as a private initiative, initially 88 companies founded the **Japan Hydrogen Association** (Japan Hydrogen Association 2021). By August 2021, the association had significantly grown, representing now 189 companies and 64 municipalities, universities and associations. Already in 2018, 11 companies, including hydrogen station operators, automobile manufacturers, and financial investors, established **Japan H2 Mobility (JHyM)** in order to promote the development of hydrogen stations to accelerate the dissemination of FCVs in Japan. With support from METI, JHyM has advanced the expansion of hydrogen filling stations (METI 2018).

5.3 International Partnerships

Japanese public and private entities are engaged in the most relevant **international hydrogen initiatives**. Japan is part of the government-led **International Partnership for Hydrogen and Fuel Cells in the Economy (IPHE)** and the **Clean Energy Ministerial Hydrogen Initiative (CEM H2I)**. In October 2021, METI and NEDO hosted the ***Fourth Hydrogen Energy Ministerial Meeting***, which was initiated by METI in 2018 and aims to promote international cooperation on the production and use of hydrogen. Furthermore, Japan is a core coalition member of **Mission Innovation**, which in June 2021 launched the ***"Clean Hydrogen" Mission*** at the Sixth Mission Innovation Ministerial. The Clean Hydrogen Mission targets the reduction of clean hydrogen, a term that is loosely specified to include both blue and green hydrogen, end-use costs to 2 USD/kg by 2030 and the establishment of at least 100 large-scale integrated hydrogen valleys worldwide. Moreover, Japan forms part of the IEA's Technology Collaboration Programme on Advanced Fuel Cells.

Japan has agreed to several bilateral partnerships as well. For example, the Japanese Ministry of Economy, Trade and Industry (METI) has been closely cooperating with the German Federal Ministry for Economic Affairs and Energy (BMWi) since 2016, since 2019 within the framework of the Japanese-German Energy Partnership (adelphi 2021). Hydrogen represents one of the major focal topics addressed by the partnership. At the regional governmental level, the prefecture of Fukushima and the region of North Rhine Westphalia in Germany have been exchanging best practices on regional energy transition since 2013, also covering hydrogen-related issues. In 2017, the energy agencies of both regions signed an agreement to accelerate the partnership and strengthen its industrial dimension by involving experts, local businesses, clusters and research institutes, thereby facilitating B2B activities, bilateral expert workshops and access to trade fairs (EU-Japan Centre 2021d).

Also, NEDO is not only carrying out domestic projects, but is also active worldwide. Currently about a dozen projects are being realized in Europe. NEDO has a Representative Office in Europe, which was established in Paris in 1998. Its main purpose is to "monitor the European technological development in the fields covered by NEDO, strengthen relationships in Europe with key participants in the energy, industrial technology and environmental areas, and promote respective activities." Further, the office represents NEDO at major events in the region and disseminates information about NEDO's activities (NEDO 2019).

Since 1991, the French Agency for Ecological Transition ADEME and NEDO have cooperated in the field of R&D policies for energy and environment. Cooperation takes the form of joint seminars on topics such as clean hydrogen and renewable energy among others, which bring together representatives of companies and research institutes from both countries (EU-Japan Centre 2021c).

In the field of hydrogen, NEDO currently supports a basic research project for the development of analysis technology for electrolysis (ANNEX30) under the IEA's Advanced Fuel Cell Technology Collaboration Programme which involves stakeholders such as Nel Hydrogen, SINTEF, Forschungszentrum Jülich, DLR Stuttgart, Fraunhofer ISE, Siemens, Hydrogenics, Thyssenkrupp, Greenerity, Asahi Kasei and Yokohama National University, amongst others. Already in 2010, NEDO and the German NOW GmbH signed a Memorandum of Understanding for information exchange on FCs and hydrogen (NEDO 2021).

International private sector initiatives are also growing in the field of hydrogen. Several Japanese companies are part of the **Hydrogen Council**, a global, CEO-led initiative of more than 100 leading energy, transportation, industrial and investment companies that since 2017 has been promoting the development of a hydrogen economy.

There are several examples for cooperation among Japanese and European companies in the field of hydrogen (EU-Japan Centre 2021). For example, the Japanese shipping and shipbuilder Tsuneishi group and the Belgian shipping and logistics company Compagnie Maritime Belge (CMB) have been collaborating on the development of hydrogen-powered vessels for the Japanese market since 2019. Due to the successful cooperation on the development of a passenger hydrogen ferry, the companies agreed to establish a joint venture in 2021 to jointly pursue further projects (EU-Japan Centre 2021a). In partnership with voestalpine, Primetal Technologies, a subsidiary of Mitsubishi Heavy Industries, is also constructing a steel production plant fuelled by hydrogen in Austria (EU-Japan Centre 2021). Mitsubishi Heavy Industries is also part of the Hamburg Green Hydrogen Hub consortium which in turn is part of Hydrogen Network Hamburg (Wasserstoffverbund Hamburg) (MHI 2021).

6. Hydrogen production

In its Green Growth Strategy, Japan expects a demand for 3 million tons of hydrogen per year by 2030 and 20 million tons by 2050. In order to satisfy this demand, the Japanese government supports the build-out of national production and the establishment of international hydrogen value chains, including both fossil and green hydrogen. However, Japan's capacity for domestic hydrogen production, especially for green hydrogen, is strongly limited due to scarcity of suitable land. As some countries within the EU, Japan is thus expected to become a large importer of hydrogen. The comparably small amounts of domestically produced hydrogen will most likely be exclusively used for domestic purposes. Therefore, Japan is not expected to become a hydrogen exporter. The following chapter will thus not focus on production potentials but provide an overview over the status of technological development and relevant demonstration projects.

6.1 Green hydrogen

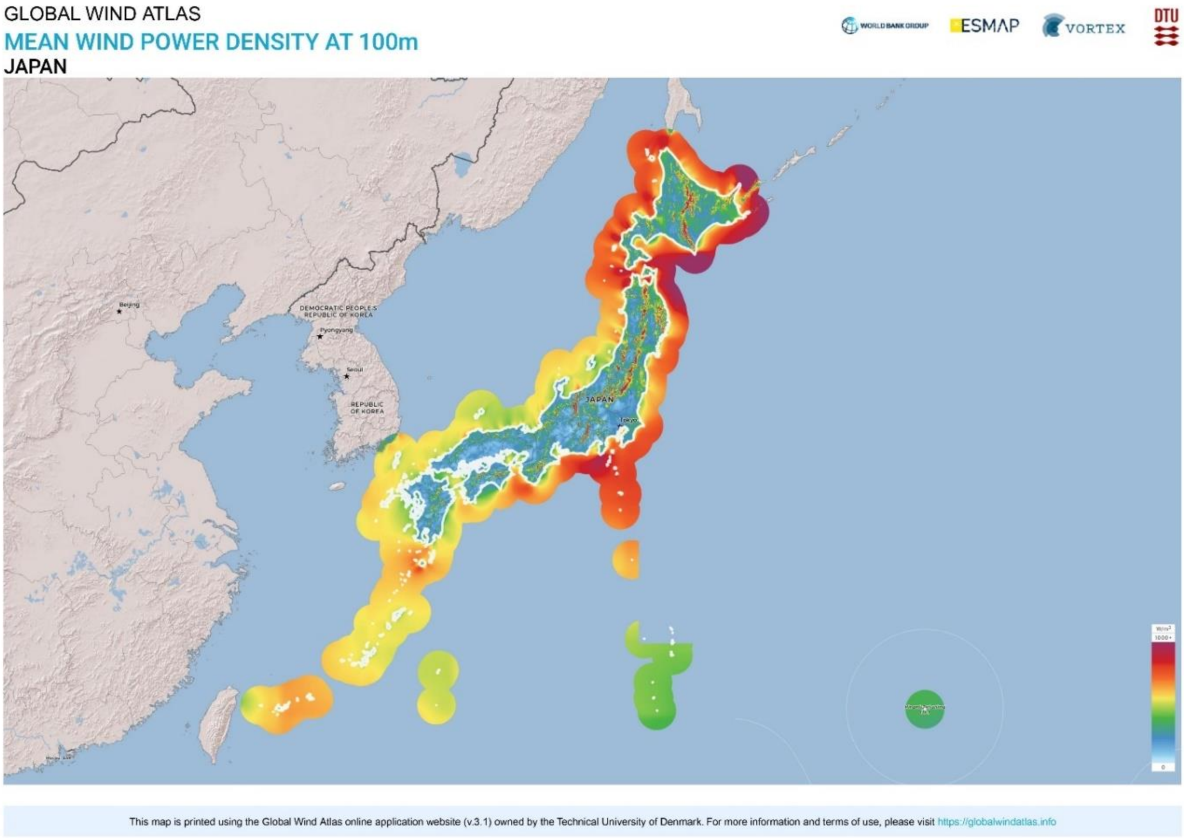
While most of the Japan's (NEDO 2021) hydrogen production is based on natural gas, the country also focuses on green hydrogen production. As of today, there are 19 electrolysis plants (~15 MW) and one plant for biomass gasification (269 nm² H2/h). Two more electrolysis plants (4.5 MW) are currently planned or under construction. Due to limited domestic renewable energy resources, Japan will need to largely focus on international green hydrogen supply chains to guarantee supply for the domestic market.

Figure 2 shows the potential for solar generation and Figure 3 for wind generation in Japan. Whilst renewable energy production is set to increase, with a renewable power supply target of 36-38% by 2030, the limited space and challenging geography (e.g. mountainous terrain, steeply sloping coastline) are an impediment to renewables deployment. In a recent study evaluating suitable land for solar and onshore wind, total available land was calculated to be 3,428 km2 (0.9% of contiguous land in Japan). Furthermore, in 72% of this land, there was deemed to be potential competition with other projects or between solar and wind energy (Asano, Obane und Nagai 2020). With regard to other forms of renewable energy production, there is significant theoretical capacity for offshore wind. Due to steep coastlines, Japan is however not well suited for bottom-fixed offshore wind turbines. Therefore, Japan is developing floating offshore wind turbines to increase its offshore wind capacity.

Figure 2: Photovoltaic power potential of Japan

Source: Map obtained from the Global Solar Atlas 2.0, a free, web-based application is developed and operated by the company Solargis s.r.o. on behalf of the World Bank Group, utilizing Solargis data, with funding provided by the Energy Sector Management Assistance Program (ESMAP). For additional information: https://globalsolaratlas.info

Figure 3: Wind power potential in Japan



Source: Map obtained from the Global Wind Atlas 3.0, a free, web-based application developed, owned and operated by the Technical University of Denmark (DTU). The Global Wind Atlas 3.0 is released in partnership with the World Bank Group, utilizing data provided by Vortex, using funding provided by the Energy Sector Management Assistance Program (ESMAP). For additional information: https://globalwindatlas.info

One of the most prominent projects is the *Fukushima Hydrogen Energy Research Field* (FH2R) in Namie Town. There, since March 2020, a 10 MW alkaline electrolyser provided by AsahiKasei has been producing green hydrogen from a 20-MW solar power facility as well as grid electricity (up to 1,200 Nm^3 of hydrogen per hour) (Power Engineering 2020). The 10MW electrolyser was the largest capacity installation in the world at the time of opening. The project will supply hydrogen for stationary FCs and transport applications. It has furthermore been announced that an offshore wind farm and hydrogen plant will be built off the coast of Hokkaido (MUKANO 2021). Once operational – expected for 2024 - the plant is expected to produce approximately 550 tons of hydrogen a year. The hydrogen would be used domestically for electricity generation.

In June 2021, a consortium of six companies were additionally selected to develop a 16.8 MW floating offshore wind farm off the coast of the Nagasaki Prefecture (Frangoul 2021). Even though this project is not aimed at hydrogen production, it demonstrates the strong Japanese interest in floating offshore wind. If commercially viable, this technology could increase Japan's green hydrogen production capabilities. It is worth noting that Japan is also actively researching photocatalysis, in which water is electrochemically split into its constituents, hydrogen and oxygen. Photocatalytic water splitting was first discovered by Akira Fujishima und Kenichi Honda in 1972 and represents an alternative to hydrogen production by electrolysis. NEDO and the Japan Technological Research Association of Artificial Photosynthetic Chemical Process (ARPChem) launched construction of a test facility in August 2019 with research and industry partners, combining a photocatalyst reaction system consisting of a two-scale photocatalytic water decomposition panel reactor with a hydrogen/oxygen separation module. The demonstration project successfully demonstrated that solar energy could produce a gas that could in turn be converted to hydrogen to provide a steady supply of energy independent of solar radiation. The gas is converted into hydrogen at an efficiency of 73%. The results of the study were published in August, the next step is to develop new membranes that increase efficiency to enable cost-effective hydrogen production from solar energy (NEDO 2021).

6.2 Blue hydrogen

Blue hydrogen production and supply chains are integral to Japan's short- and medium-term hydrogen targets, whilst a stronger role for green hydrogen is foreseen in the long-term. Japan especially aims for the usage of blue hydrogen to accelerate the build-out of hydrogen infrastructure. In addition, Japan's major international supply chain projects, which are a crucial basis for the Japanese hydrogen economy, are at the time of writing all focused on blue or grey hydrogen. As Japan is heavily dependent on natural gas imports with no significant domestic resources, most future demand for blue hydrogen would need to be met by imports.

Of particular importance to Japan is CCS/CCU technology to allow for the low-carbon use of fossil fuels in hydrogen production. Japan is currently implementing a range of CCS-based hydrogen projects. One of these projects, which will be discussed in more detail below, is the HySTRA project, designed to supply blue hydrogen from Australia to Japan. In the first pilot stage, the project will test the capabilities of producing hydrogen via coal in Australia and transporting it in liquified form to Japan. In the commercial phase, the carbon dioxide produced during the process is to be captured (Suda 2021).

6.3 CCS potentials

Japan sees a considerable future potential for the usage of carbon capture and storage (CCS) as well as carbon capture, utilization and storage technologies (CCUS). In its Green Growth Plan, Japan sets the aim of achieving a 30% market share for CCS technologies by 2050. Despite the strong technological focus on CCS technology, Japan's domestic potential for storage is very limited due to geological conditions. The IEA assumes a storage capacity of 15 Gt, which would not even be sufficient for a fraction of current annual Japanese CO_2 emissions (IEA 2021). Japan is therefore looking into a potential export of CO_2 from CCS projects.

During COP26, the Japan Pavillon displayed the country's first large scale CCS demonstration project: the Tomakomai CCS Demonstration Project, which operated from 2016 to 2019 (MOEJ 2021). It enabled a cumulative injection of 300,000 tonnes. In this project, gas containing CO_2 from a refinery was transported by pipeline to the capture facilities, and the CO_2 is compressed and stored 3-4 km offshore in two sub-seabed reservoirs by two-directional wells. Another large-scale project is conducted by Toshiba Energy Systems & Solutions Corporation and 17 partners at Mikawa Power Plant in Omuta, Fukuoka prefecture. Fuelled by palm kernel shells (PKS), the project sets out to establish the first bio energy power plant that utilises large-scale Carbon Capture and Storage (BECCS). It sits within the "Demonstration of Sustainable CCS Technology Project", which Japan's Ministry of Environment (MOE) sponsors. The facility is expected to capture more than 500 tons of CO_2 a day (Toshiba 2020).

At the G20 Ministerial Meeting on Energy Transitions and Global Environment for Sustainable Growth in Karuizawa, June 2019, Japan and the EU agreed on sharing information on CCUS. Furthermore, Japan signed a Memorandum of Cooperation (MOC) with Canada, Australia and Indonesia that each include CCUS technologies. With the US, Japan signed a MOC on CCS and agreed on research and development collaboration for CCS deployment. The cooperation with Australia within the framework of the HySTRA project includes, moreover, a hydrogen energy supply chain project where Australian brown coal will be converted into liquid hydrogen with CCS for export to Japan (Kawaguchi 2019).

Additionally, the revised Roadmap for Carbon Recycling Technologies was released by METI in July 2021. The document sets out, and contributes to, the dissemination and expansion of Carbon Recycling, and in doing so seeks to spur innovation. (METI 2021). On October 4th, 2021, METI and NEDO jointly held the Third International Conference on Carbon Recycling 2021 (METI 2021).

7. International hydrogen and ammonia supply chain development

For Japan, the strategic development of international hydrogen supply chains plays a major role due to the country's ambitious plans for hydrogen application and limited domestic production capacities. In this context, the Japanese government is promoting two major projects in particular (Agency for Natural Resources and Energy 2020), one in Brunei, which entered operation first, and one in Australia.

7.1 Brunei

The first of these is the *Advanced Hydrogen Energy Chain Association for Technology Development* (**AHEAD**) grey hydrogen project (AHEAD 2021), which is supported by NEDO. Under this project, by applying an *Organic Chemical Hydride Method*, natural gas-based hydrogen will be imported from Brunei to Kawasaki in Japan. The hydrogen is converted into methylcyclohexane (MCH) by bonding to toluene and shipped to Kawasaki in ISO containers, in order for the MCH to be then separated back into hydrogen and toluene, which will be transported back to Brunei for repeated use as a hydrogen carrier. The first shipment of hydrogen took place in 2019. At that time, the conversion plant in Japan was not yet operational. Since May 2020, the imported hydrogen has been used for energy production in Japan (AHEAD 2021).

7.2 Australia

The second major project that the Japanese government is currently pursuing is *CO2 Free Hydrogen Energy Supply Chain Technology Research Association* (**HySTRA**) to supply blue hydrogen from Australia to the unloading terminal in Kobe. It is being implemented by a consortium of Kawasaki, Shell Japan and other Japanese companies, also with support by NEDO. In the first pilot stage, the project will test the capabilities of producing hydrogen via coal in Australia and transporting it liquified to Japan. In the commercial phase, the associated CO_2 shall be captured. As part of this project, the world's first transport ship for liquified hydrogen, the *Suiso Frontier* built by Kawasaki Heavy Industries, was inaugurated in December 2019. It shall transport 1,250 m^3 of liquid hydrogen at -253 °C (HySTRA 2021).

Further, Japan and Australia plan to establish a clean fuel ammonia supply chain, with the aim to achieve CO_2-neutrality through CCS and compensation measures. Japan Oil, Gas and Metals Mineral Resources Organization (JOGMEC), Marubeni, Hokuriku Electric Power Company, Kansai Electric Power Company and the Australian Woodside Energy Ltd. seek to jointly undertake a commercialization survey of the entire ammonia supply chain, ranging from production in Australia, to marine transportation to Japan and utilization as fuel for power generation and ships. The companies signed a respective joint research agreement in July 2021 (EU-Japan Centre 2021).

In September 2021, Japan's biggest hydrogen supplier Iwatani Corp announced a feasibility analysis of developing a supply chain of low-cost green liquefied hydrogen between Japan and Australia. Iwatani, Kawasaki Heavy Industries, Kansai Electric Power Co Inc and Marubeni Corp signed a respective MoU with the Australian companies Stanwell Corp and APT Management Services Pty Ltd. Renewable energy-based hydrogen is to be produced on a large scale and then liquefied at the Port of Gladstone in Queensland. From there it will be transported to Japan. The project aims to produce at least 100 tons of hydrogen a day around 2026. By 2031 it could be scaled to a capacity of 800 tons/day (Reuters 2021).

7.3 United Arab Emirates

Recently, Japan has further expanded its alliances for the development of hydrogen supply chains. Due to its large fossil fuel but also renewable energy resources, the United Arab Emirates (UAE) represent a potential source for low-cost hydrogen for Japan. In April 2021, Vice Minister Ejima (METI) and H.E. Suhail Mohamed Al Mazrouei, UAE Minister of Energy and Infrastructure, signed a Memorandum of Cooperation (MoC) in the field of hydrogen. It stipulates the cooperation and information exchange among the two ministries on hydrogen policies, the establishment of hydrogen supply chains, as well as the development of regulations and standards (METI 2021). In January 2021, Minister Kajiyama (METI) and H.E. Dr. Sultan Ahmed Al Jaber, CEO, Abu Dhabi National Oil Company (ADNOC) and UAE Minister of Industry and Future Technology discussed opportunities for enhanced cooperation in the fields of hydrogen, ammonia and carbon recycling. To accelerate bilateral cooperation in the fields of fuel ammonia and carbon recycling, a MoC was concluded between METI and ADNOC, from which Japan currently purchases about 25% of its total crude oil (METI 2021). In July, the ministers accompanied the signing of a Joint Study Agreement (JSA) between Japanese companies and government agencies (INPEX, JERA, JOGMEC) and ADNOC for research and further development of projects related to the use of ammonia as fuel (ADNOC 2021). It represents the cornerstone for a scheduled feasibility study for producing ammonia synthesized from hydrogen produced by reforming natural gas in Abu Dhabi, whereby captured CO_2 is to be used for enhanced oil recovery (CO2 EOR). The ammonia is then to be transported to Japan (EU-Japan Centre 2021).

7.4 Russia

Russia represents another partner of Japan on international ammonia and hydrogen supply chains. During the *Eastern Economic Forum* that was held in September 2021 in Vladivostok, METI and Russian Gazprom signed a MoC on hydrogen, ammonia, CCS, and CCU, which will further deepen pre-existent cooperation among both countries. Since 2007, 13 joint coordination committee meetings took place between Gazprom and METI, which serve as a forum for discussions on joint private projects. Further, from 2021 to 2023, Japan and Russia will cooperate in a program focusing on science and technology development with special emphasis on hydrogen projects (METI 2021). In July 2021, Toyo Engineering, Itochu, Narais an Irkutsk Oil Company and Japan Oil Natural Gas and Metal Mineral Resources Organization (JOGMEC) announced that they will start the second phase of a commercialization survey dealing with the establishment of a blue ammonia value chain between East Siberia and Japan that was carried out in FY 2020 (EU-Japan Centre 2021).

7.5 Canada

Another cooperation has been established among Japanese and Canadian companies, which signed a MoU to build a hydrogen production plant with CCS in Alberta in September 2021 (Electric Energy Online 2021). The plant with a capacity of 165,000 tonnes of hydrogen per year is to be built near Edmonton in the second half of the 2020s. Blue hydrogen from natural gas will then be exported to Japan in the form of ammonia. Captured CO2 is to be stored underground, with Shell planning a CCS project in Alberta with a capacity of 10 million tonnes of CO2 annually. The project is part of Japan's 2021 roadmap for the development of ammonia as fuel, according to which ammonia imports are to be increased to 3 million tons and 30 million tons per year by 2030 and 2050, respectively.

8. Sustainability issues

As large-scale production of hydrogen is currently not foreseen in Japan, domestic issues regarding water scarcity and production emission intensity are thus not as critical as in potential exporting countries. Overall, the future viability of CCS technology, in terms of cost competitiveness and CO_2 capture rates, will be of central importance to the climate impact of Japan's hydrogen economy, as many hydrogen projects that are currently planned or under development rely on CCS technology.

8.1 Sustainability criteria of hydrogen production

An official definition for clean hydrogen is currently still being discussed in Japan. The term "CO_2-free hydrogen" is commonly used for hydrogen produced with low CO_2 emissions. This usually refers to hydrogen produced by fossil fuels in combination with CCS or by renewable electrolysis, even though nuclear is not explicitly excluded. A government committee on CO_2-free hydrogen considered the necessity for establishing a standard and certification scheme in Japan. The revised version of the Strategic Roadmap for Hydrogen and Fuel Cells (released in March 2019) mentioned the need for CO_2 emission reduction along the whole hydrogen supply chain. Yet, no specific actions for establishing a standard or a certification scheme are observed until now (Jensterle et. al. 2019).

Regional certificate systems for CO_2-free hydrogen have also emerged. In April 2018, the Aichi Prefecture began its own, with two categories, which focuses on direct emissions from hydrogen production. The first, included hydrogen that had been produced using renewable electricity via water electrolysis or from steam reforming via biogas. In the second, certificate systems were used to compensate CO_2 emissions. Either with green electricity certification to compensate the use of grid electricity used for water electrolysis in hydrogen production, or via the J-Credit which compensates for fossil fuel induced emissions. The J-Credit certifies GHG emission reductions from sinks. Issued by the government the sinks range from forest management to energy-saving devices. In order for companies to attain either certificate they have to undergo a review process from a third party (Jensterle et. al. 2019). The scheme has so far been used to certify around 900 projects.

On the multilateral level, Japan is a member of the International Partnership for Hydrogen and Fuel Cells in the Economy (IPHE). With a main focus on the harmonisation of regulation, codes and standards, the intergovernmental partnership seeks any sector or operation which could transition to a hydrogen based clean energy system (Jensterle et. al. 2019). Thereby, Japan is involved in an IPHE Taskforce, launched in 2020, with the goal of developing a globally accepted methodology to calculate the carbon footprint of hydrogen (van Hulst 2019).

Moreover, the first Hydrogen Energy Ministerial Meeting was initiated and hosted by the Japanese government in Tokyo in October 2018 and saw the participation 21 countries. As one focal point, Japan advocates for international cooperation on technologies and the harmonization of regulation, codes and standards in order to speed up cost reductions for hydrogen supply and products. However, specific sustainability criteria are not further elaborated within this initiative (Hydrogen Energy Ministerial Meeting 2021).

8.2 Environmental Impact Assessment

The Environmental Impact Assessment Act outlines the requirements for energy projects (Higuchi und Norifumi 2021). Currently, this covers wind power projects of more than 7.5 MW and is expected to apply to solar power projects of more than 40 MW in the future. The act requires a survey, forecast and evaluation of possible environmental changes to be carried out in order to adequately assess the risks.

8.3 Socio-economic issues

Whilst the whole population of Japan has access to electricity, there are minor cases of energy poverty. A recent study showed that, since the 2000s, energy poverty has increased, particularly so for single-elderly and mother-child households (Okushima 2017). In addition, hidden energy poverty and regional energy poverty are both issues, with underconsumption hiding the issue. The northern and southern regions of Japan suffer more (Okushima 2019) (Castano-Rosa und Okushima 2021). If Japan is to become a hydrogen-based economy, energy costs (for industry and consumers) will therefore be an important issue.

Bibliography

adelphi. *Energy Partnership with Japan and Korea.* November 2021. https://www.adelphi.de/en/project/energy-partnership-japan-and-korea.

ADNOC. *ADNOC and Three Japanese Companies to Explore Hydrogen and Blue Ammonia Opportunities.* 2021. https://www.adnoc.ae/news-and-media/press-releases/2021/adnoc-and-three-japanese-companies-to-explore-hydrogen-and-blue-ammonia-opportunities.

Agency for Natural Resources and Energy. *Hydrogen Energy Update A promising image of a "hydrogen-based society" is emerging now.* 2020. https://www.enecho.meti.go.jp/en/category/special/article/detail_153.html.

AHEAD. 2021. https://www.ahead.or.jp/en/.

Asano, Kenji, Hideaki Obane, und Yu Nagai. „Assessing land use and potential conflict in solar and onshore wind energy in Japan." *Renewable Energy*, 2020: 842-851.

Castano-Rosa, Raúl, und Shinichiro Okushima. „Prevalence of energy poverty in Japan: A comprehensive analysis of energy poverty vulnerabilities." *Renewable and Sustainable Energy Reviews* 145 (2021).

Central Intelligence Agency. *The World Factbook.* 2021. https://www.cia.gov/the-world-factbook/countries/japan/#economy.

D'Ambrogio, Enrico. *EPRS | European Parliamentary Research Service.* 2020. https://www.europarl.europa.eu/RegData/etudes/BRIE/2020/651951/EPRS_BRI(2020)651951_EN.pdf.

Electric Energy Online. *Mitsubishi Corporation and Shell Sign MoU to Collaborate on Hydrogen Plans in Alberta.* 2021. https://electricenergyonline.com/article/energy/category/biofuel/83/918011/mitsubishi-corporation-and-shell-sign-mou-to-collaborate-on-hydrogen-plans-in-alberta.html.

EU-Japan Centre. *Case Studies: EU-Japan Industrial Cooperation for Decarbonization.* 24th. November 2021. https://www.eu-japan.eu/climate.

—. *Economic Overview.* 2021b. https://www.eubusinessinjapan.eu/why-japan/background/economic-overview.

—. *Energy Transition Agencies.* November 2021d. https://www.eu-japan.eu/publications/energy-transition-agencies-fukushima-x-north-rhine-westphalia.

—. *Hydrogen Steel Plant Voestalpine X Mitsubishi Heavy Industries.* 24th. November 2021. https://www.eu-japan.eu/publications/hydrogen-steel-plant-voestalpine-x-mitsubishi-heavy-industries.

EU-Japan Centre. *Hydrogen-powered vessels CMB X Tsuneishi Group.* 2021.

—. *Hydrogen-Powered Vessels: CMB X Tsuneishi Group.* 24th. November 2021a. https://www.eu-japan.eu/hydrogen-powered-vessels-cmb-x-tsuneishi-group.

—. *Japanese Industry and Policy News July-August 2020.* 2020. https://www.eu-japan.eu/sites/default/files/publications/docs/jipn_jul.-aug.pdf.

—. *JAPANESE INDUSTRY AND POLICY NEWS June and July 2021.* 2021. https://www.eu-japan.eu/sites/default/files/publications/docs/june-july_2021.pdf.

—. *R&D Policies for Green Innovation.* 24th. November 2021c. https://www.eu-japan.eu/publications/rd-policies-green-innovation-ademe-x-nedo.

Frangoul, Anmar. *CNBC.* 2021. https://www.cnbc.com/2021/08/24/japan-targets-floating-wind-farms-for-its-deep-coastal-waters.html.

Geitmann, Sven. *Japan: Forcierung der SOFC-Technologie.* 2018. https://www.hzwei.info/blog/2018/03/09/japan-forcierung-der-sofc-technologie/#more-7309.

Global CCS Institute. *Facility Data.* 2021. https://co2re.co/FacilityData.

Higuchi, Wataru, und Takeuchi Norifumi. 2021. https://thelawreviews.co.uk/title/the-renewable-energy-law-review/japan.

Hydrogen Energy Ministerial Meeting. *Hydrogen Energy Ministerial Meeting Landing Page.* 2021. https://hem-2021.nedo.go.jp/_en/.

HySTRA. 2021. http://www.hystra.or.jp/en/.

IEA. *The world has vast capacity to store CO2: Net zero means we'll need it.* 18th. November 2021. https://www.iea.org/commentaries/the-world-has-vast-capacity-to-store-co2-net-zero-means-we-ll-need-it.

IFES. *www.electionguide.org.* 2021. https://www.electionguide.org/countries/id/109/.

IRENA. *Renewable energy auctions in Japan: Context, design and result.* 2021. https://irena.org/-/media/Files/IRENA/Agency/Publication/2021/Jan/IRENA_Auctions_Japan_2021.pdf.

Japan Hydrogen Association. *Japan Hydrogen Association - Overview.* 2021. https://www.japanh2association.jp/en/.

Jensterle et. al. . „The role of clean hydrogen in the future energy systems of Japan and Germany." https://www.adelphi.de/de/system/files/mediathek/bilder/The%20role%20of%20clean%20hydrogen%20in%20the%20future%20energy%20systems%20of%20Japan%20and%20Germany%20-%20Study.pdf, 2019.

Kankyo. *NEDO TO DEVELOP 1400°C CLASS "HYDROGEN POWER GENERATION SYSTEM" THAT ACHIEVES 68% POWER GENERATION EFFICIENCY.* 2020. https://www.kankyo-business.jp/news/026177.php.

Kankyo. „改正地球温暖化対策推進法が成立　「2050年カーボンニュートラル」を明記.“ *Kankyo*, May 2021.

Kankyo. „日本の温室効果ガス削減目標、「2030年度46%削減」に引き上げ.“ *Kankyo*, April 2021.

Kawaguchi, Yukihiro. *Overview of Japanese CCUS Policy.* http://copjapan.env.go.jp/cop/cop25/assets/pdf/s30_JCCS/05_YukihiroKawaguchi_COP25_JAPANPAVILION_CCS_side_event_r1.pdf: METI, 2019.

METI. *"Green Growth Strategy Through Achieving Carbon Neutrality in 2050" Formulated.* 2021. https://www.meti.go.jp/english/press/2021/0618_002.html.

—. *Basic Hydrogen Strategy.* 2017. https://www.meti.go.jp/english/press/2017/pdf/1226_003b.pdf.

—. *General Energy Statistics.* 2021. https://www.enecho.meti.go.jp/statistics/total_energy/xls/stte_2019a.xlsx.

METI. „Green Growth Strategy Through Achieving Carbon Neutrality in 2050.“ 2021.

—. *Japan H2 Mobility, a Company for Development of Hydrogen Stations, Established.* 2018. https://www.meti.go.jp/english/press/2018/0305_001.html.

METI. *Japan policy updates (in the framework of a bilateral workshop).* May 2021.

METI. „Japan's Energy 2020.“ https://www.enecho.meti.go.jp/en/category/brochures/pdf/japan_energy_2020.pdf, 2020.

—. *METI and Gazprom Sign a Memorandum of Cooperation on Hydrogen, Ammonia, CCS, and CCU/Carbon Recycling.* 2021. https://www.meti.go.jp/english/press/2021/0908_001.html.

—. *Minister Kajiyama Holds Meeting with H.E. Dr. Sultan Ahmed Al Jaber, CEO, Abu Dhabi National Oil Company (ADNOC), and Minister of Industry and Advanced Technology, UAE.* 2021. https://www.meti.go.jp/english/press/2021/0114_001.html.

—. *Next-generation renewable energy.* 2021. https://www.meti.go.jp/english/policy/energy_environment/global_warming/ggs2050/pdf/01_offshore.pdf.

—. *Overview of Japan's Green Growth Strategy.* 2021. https://www.mofa.go.jp/files/100153688.pdf.

—. *Promising Sea Areas and Sites Selected for Targeted Promotion.* 2019. https://www.meti.go.jp/english/press/2019/0730_001.html.

—. *Roadmap for Carbon Recycling Technologies Revised.* 2021. https://www.meti.go.jp/english/press/2021/0726_003.html.

—. *Selection of Operators for the Offshore Wind Power Generation Project off Goto City, Nagasaki Prefecture.* 2021. https://www.meti.go.jp/english/press/2021/0611_004.html.

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

—. *Strategy for Developing Hydrogen and Fuel-Cell Technologies Formulated.* 2019. https://www.meti.go.jp/english/press/2019/0918_001.html.

—. *Third International Conference on Carbon Recycling 2021 Held.* 2021. https://www.meti.go.jp/english/press/2021/1006_002.html.

MHI. *Mitsubishi Heavy Industries Partner in Newly Established Hamburg Hydrogen Network to 'Make Hamburg Greener'.* 26th. March 2021. https://www.mhi.com/news/21042602.html.

Ministry of Foreign Affairs of Japan. *Free Trade Agreement (FTA) / Economic Partnership Agreement (EPA) and Related Initiatives.* 2. December 2020. https://www.mofa.go.jp/policy/economy/fta/index.html.

MOEJ. *Japan Pavilion COP 26.* 2021. http://copjapan.env.go.jp/cop/cop26/en/category/rural/.

MUKANO, RYO. *Offshore wind to power Japan's biggest green hydrogen plant, Nikkei.* 2021. https://asia.nikkei.com/Business/Energy/Offshore-wind-to-power-Japan-s-biggest-green-hydrogen-plant2.

NEDO. „Potential Cooperation Areas and Potential Joint Green Hydrogen Projects." 2021.

—. *Profile of NEDO.* 2021. https://www.nedo.go.jp/content/100898872.pdf.

—. *Representative Office in Europe.* 2019. https://www.nedo.go.jp/english/introducing/paris_index.html.

—. *World's first successful demonstration of solar hydrogen production on a 100 m2 scale using artificial photosynthesis.* 26th. August 2021. https://www.nedo.go.jp/news/press/AA5_101473.html.

—. *World's First Successful Technology Verification of 100% Hydrogen-fueled Gas Turbine Operation with Dry Low NOx Combustion Technology.* 2020. https://www.nedo.go.jp/english/news/AA5en_100427.html.

Neely, Caylon. *Japan Industry News: Japanese political system.* 2016. https://www.japanindustrynews.com/2016/06/japanese-political-system/.

Nikkei. *cost reduction to spread renewable energy to start a new purchase system for electricity.* 2020. https://www.nikkei.com/article/DGXMZO60067930V00C20A6EA4000/.

Nikkei. „Future of nuclear power looms over Japan's LDP leadership race." *The Nihon Keizai Shimbun*, September 2021.

—. *Japan's first commercial hydrogen power plant to open near Mount Fuji.* 2021. https://asia.nikkei.com/Business/Energy/Japan-s-first-commercial-hydrogen-power-plant-to-open-near-Mount-Fuji.

Okushima, Shinichiro. „Gauging energy poverty: A multidimensional approach.“ Herausgeber: Elsevier. *Energy* 137(C) (2017): 1159-1166.

Okushima, Shinichiro. „Understanding Regional Energy Poverty in Japan: A Direct Measurement Approach.“ *Energy Build* 193 (2019): 174-184.

Pekkanen, Robert, und Saadia Pekkanen. *Japanese Politics: An Introduction.* The Oxford Handbook of Japanese Politics, 2021.

Power Engineering. *Japanese launch world's largest-class hydrogen production unit.* 2020. https://www.power-eng.com/emissions/japanese-launch-worlds-largest-class-hydrogen-production-unit/#gref.

Prime Minister's Office of Japan. *温室効果ガスの削減目標及び緊急事態宣言等についての会見.* 22. April 2021. https://www.kantei.go.jp/jp/99_suga/statement/2021/0422kaiken.html.

Renewable Energy Institute. „Proposal for 2030 Energy Mix in Japan (First Edition).“ 2. September 2020. https://www.renewable-ei.org/pdfdownload/activities/REI_Summary_2030Proposal_EN.pdf.

—. *Statistics | Energy.* 2021. https://www.renewable-ei.org/en/statistics/energy/?cat=electricity.

—. *Statistics | RE.* 2021. https://www.renewable-ei.org/en/statistics/re/?cat=wind.

Reuters. „Factbox: Key policies of Japan's next PM Kishida, a consensus builder.“ *Reuters*, September 2021.

Reuters. „Japan boosts renewable energy target for 2030 energy mix.“ July 2021.

—. *Japan, Australia firms look to build large-scale green liquefied hydrogen supply chain.* 2021. https://www.reuters.com/business/sustainable-business/japan-australia-firms-look-build-large-scale-green-liquefied-hydrogen-supply-2021-09-15/.

Samanta, Koustav, und Fathin Ungku. *Southeast Asian nations tout green power links ahead of COP26, The Japan Times.* 2021. https://www.japantimes.co.jp/news/2021/10/27/asia-pacific/asean-green-power-grid/.

Suda, Rieko. *Japan's Iwatani mulls blue hydrogen output in Hokkaido.* 2021. https://www.argusmedia.com/en/news/2190293-japans-iwatani-mulls-blue-hydrogen-output-in-hokkaido.

The Japan Times. „Japan sets 60% target for nonfossil fuel energy sources by fiscal 2030.“ *The Japan Times*, July 2021.

—. *Kishida to push for Asia-wide zero emission efforts at COP26 summit.* 2021. https://www.japantimes.co.jp/news/2021/11/02/national/kishida-departs-for-cop26/.

The Japan Times. „LDP hopefuls vow to introduce nuclear fusion and small modular reactors.“ *The Japan Times*, September 2021.

Toshiba. *Demonstration Project Begins for Commercialization of Vessels Equipped with High-power Fuel Cells.* 2020. https://www.toshiba-energy.com/en/info/info2020_0901.htm.

—. *Toshiba Starts Operation of Large-Scale Carbon Capture Facility.* 2020. https://www.toshiba-energy.com/en/info/info2020_1031.htm.

Toyota. *Plan to Develop Aichi Low-carbon Hydrogen Supply Chain Moves Forward.* 2018. https://global.toyota/en/newsroom/corporate/22312931.html.

TRADING ECONOMICS. *Japan Exports By Country.* 2021. https://tradingeconomics.com/japan/exports-by-country.

van Hulst, Noe. *IPHE: THE NEXT PHASE: TURNING CLEAN HYDROGEN INTO A GLOBAL COMMODITY.* 2019. https://1fa05528-d4e5-4e84-97c1-ab5587d4aabf.filesusr.com/ugd/45185a_5624326e5efa4231b8980a50d94d042d.pdf.

World Bank Group. *World Bank national accounts data, and OECD National Accounts data files.* 2021. https://data.worldbank.org/indicator/NY.GDP.MKTP.CD?end=2020&start=2015.

World Bank. *World Bank Global Electrification Database.* 2019. https://data.worldbank.org/indicator/EG.ELC.ACCS.ZS?locations=JP.