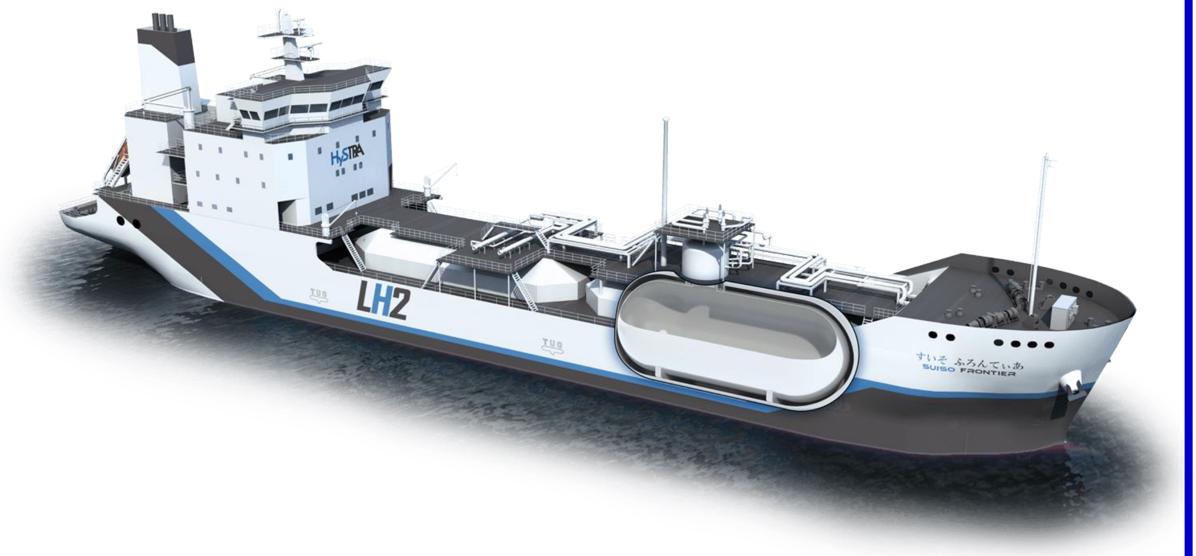
EU-Japan Centre for Industrial Cooperation

Building a Resilient Hydrogen Economy:
Securing Clean Hydrogen Together

Tokyo, 03 April 2023

Sven Kevin van Langen



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Preface

This report was written in the context of the EU-Japan Centre for Industrial Cooperation's MINERVA fellowship, a 6-month in-house research scheme in Japan funded by the European Commission's Directorate General for Internal Market, Industry, Entrepreneurship and SMEs (DG GROW) with additional support by Japan's Ministry of Economy, Trade and Industry (METI). The author has conducted his research and prepared this publication with full academic freedom, and the funding body has not exerted any influence over the content, methodology, or conclusions presented herein.

The report is intended for a diverse audience, though it is mostly written with European industry in mind. The author hopes the report will also be insightful to policymakers and academia. It explores potential areas for cooperation between European and Japanese firms in developing a hydrogen economy. Specific attention is given to where cooperation can lead to increased energy security and economic resilience for both the EU and Japan as partners.

The report builds on an earlier report published under the Centre's MINERVA program by Jonathan Arias, entitled "Hydrogen and Fuel Cells in Japan" [1]. In conjuction with this report, the author monitored Japanese public policy developments related to the research topic, a summary of some of this intelligence, regarding Japan's hydrogen related foreign policy, is provided in Annex A.

About the author

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[1] Retrieved from the EU-Japan Centre for Industrial Cooperation on 15-03-2023: https://www.eu-japan.eu/sites/default/files/publications/docs/hydrogen_and_fuel_cells_in_japan.pdf

Executive Summary

There are many areas in which the European Union and Japan could cooperate when it comes to establish a resilient hydrogen economy. The European Union and Japan are in a very similar position as they are both projected to rely heavily on hydrogen imports for their energy security by 2050.

Five key areas for cooperation can be identified:

1. Research and development: Both the EU and Japan are investing heavily in research and development of hydrogen technologies, including electrolysers and transport. Joint research and development projects could accelerate progress and help to overcome technical challenges.
2. Harmonising regulations and standards: Developing harmonized and interoperable standards & regulations is essential for the widespread adoption of hydrogen technologies. The EU and Japan could work together to develop such standards & regulations to ensure compatibility and interoperability between their respective hydrogen systems. Harmonised standards are relevant both domestically in Japan and the EU, and in third countries, to develop a more resilient global supply of hydrogen.
3. Infrastructure development: Building the necessary infrastructure for hydrogen production, storage, and transportation is a significant challenge. The EU and Japan could collaborate on developing and implementing infrastructure projects that can support the growth of the hydrogen economy.
4. Market development: As the hydrogen economy continues to grow, both the EU and Japan could work together to create new markets for hydrogen and encourage the adoption of hydrogen technologies in various sectors. An important market driver might be in sustainable finance.
5. Supply chain management: Ensuring a stable and secure supply of hydrogen is critical for the success of the hydrogen economy. The EU and Japan have to collaborate on managing the global supply chain for hydrogen as the two largest net importers, including the production, transportation, and storage of hydrogen, as well as the development of hydrogen trading platforms.

Whilst there is ample opportunity to cooperate directly on a bilateral basis, there are also gains to be made by working together in third countries. Particularly, Southeast Asia, Australia, the Middle East, and Africa offer intriguing opportunities for collaboration.

Moreover, it is advisable to promote greater inter-academic and public-private partnerships for R&D in the area of hydrogen production, storage, and transport. One suggestion is for the EU-Japan Centre for Industrial Cooperation to provide more extensive support in this field, beyond its current role as the national contact point for Horizon Europe. Especially for the scenario where Japan will join Horizon Europe as an associate country it is expected that there will be an increased demand for aid in finding R&D partners. However, even in the current situation where Japan is not an associate member of Horizon Europe there is a strong interest in better R&D cooperation but a low ability by the EU’s private sector to find suitable academic partners in Japan and vice versa.

Table of Contents

Table of Figures

1. Introduction

The introduction to this study begins with a brief background on the topic studied, followed by a statement of the research objective and the methods used. Next, a background section provides details on the state-of-the-art regarding global hydrogen supply chains and Japan's role in them.

There is growing interest in hydrogen among major economies worldwide, as it is seen as a crucial fuel in a decarbonized society. Currently, hydrogen is primarily used as a feedstock in oil refining and in producing chemical fertilizers (mostly ammonia). However, as more economies aim to become carbon neutral, hydrogen is expected to fulfil new roles. It is seen as critical in decarbonizing hard-to-electrify industries and as a potentially important fuel in the transport sector in a decarbonized society. However, the majority of hydrogen is currently produced using natural gas, which accounts for a significant share of global greenhouse gas emissions. As a result, hydrogen production is currently seen as contributing to climate change. By producing hydrogen through methods that do not emit large amounts of greenhouse gases, a significant step towards decarbonization can be made, making it more likely to achieve the targets set out in the 2015 Paris Agreement.

Russia's war of aggression in Ukraine and the subsequent shocks to the natural gas and other energy markets have sparked a significant interest in low-carbon hydrogen (including non-carbon hydrogen) worldwide, particularly within the EU[i]. In addition to being an environmental matter, hydrogen production methods other than natural gas are seen as crucial for energy security. As low-carbon and non-carbon hydrogen can be produced by a more diverse range of suppliers and is not dependent on a few fossil fuel-rich countries, future hydrogen supply chains are expected to be less sensitive to geopolitical issues.

According to the International Energy Agency (IEA), the EU and Japan will become the largest importers of hydrogen by 2050, with Korea in a distant third spot [i]. Australia, the Middle East, North Africa, and Latin America are expected to become major hydrogen exporters. China and the US are anticipated to become the largest producers of hydrogen, but their production would largely be for domestic consumption. An overview is provided in Figure 1. Both the EU and Japan have a common interest in creating a diversified global supply chain for hydrogen trade to ensure their energy security and are thus natural partners in establishing new hydrogen markets.

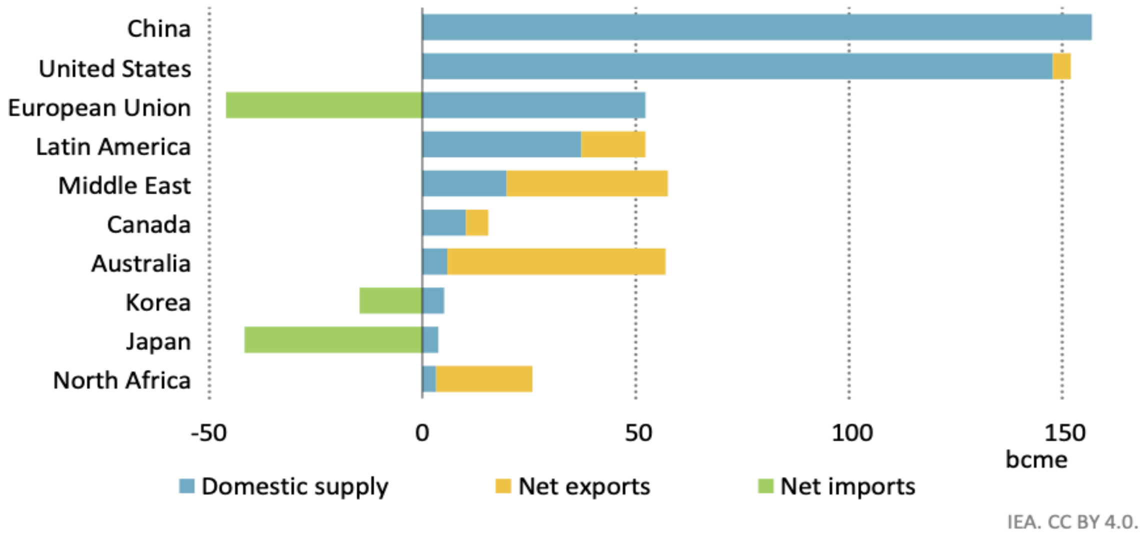

Figure 1, predictions for 2050 on major hydrogen producers, exporters, and importers in BCME according to the IEA. Copyright 2022 IEA, shared under a compatible license.

1.1. Research Objectives

This policy paper aims to explore the opportunities and threats to cooperation between Japan and the EU in developing resilient green/low-carbon hydrogen supply chains that use electrolysers for hydrogen production. To develop a comprehensive supply chain, many actors need to be involved. The paper first provides an overview of the current state of affairs of hydrogen production and what is needed to develop a global low-carbon hydrogen supply chain. Then, major areas of potential cooperation between Japan and the EU are highlighted. Industrial, governmental, and academic cooperation are all considered. Furthermore, important third parties for trilateral cooperation in the area of hydrogen production, such as the ASEAN member states, Australia, Africa, and the Middle East, are discussed. To conclude, the report aims to provide recommendations on how governments can better facilitate cooperation between actors in Japan and the EU.

1.2. Methods

This report is built using a combination of desk research and interviews.

The desk research consists of a thorough analysis of mainly government reports and reports from leading research institutes on hydrogen and renewable energy transitions, among others. Furthermore, the latest policy developments are monitored and included in this report where appropriate, e.g., when the EU and Japan signed a Memorandum of Cooperation on Hydrogen during the ongoing development of this report.

The interviews were held with a diverse range of interviewees, such as policy makers, political advisors, academic researchers, and people from industry. To allow interviewees to speak more openly, all interviewees will be kept anonymous. Some interviews were conducted unstructured, while others were conducted semi-structured. For each semi-structured interview, a unique set of questions was tailored to the interviewee.

2. Background

This first section provides background information that is necessary to understand the later considerations and recommendations. It explains what hydrogen is, what it is used for, how it is supplied to the EU and Japan and how this is expected to happen in the future, and it highlights important players in the hydrogen field now and in the future.

2.1. Hydrogen Economy

The hydrogen economy is a vision of a future in which hydrogen is used as a primary source of energy to power our homes, transportation, and industries, alongside electricity. Hydrogen is considered a promising energy source due to its high energy content, versatility, and the fact that it produces only water when burned. This means that it is a clean and renewable source of energy that does not produce harmful greenhouse gas emissions or contribute to air pollution.

To achieve a hydrogen economy, several steps must be taken. First, a hydrogen production infrastructure must be established. This can be done through the use of renewable energy sources, such as wind and solar power, to produce hydrogen through the process of electrolysis. Second, a distribution network must be built to transport hydrogen to consumers. Third, the development of hydrogen storage and fuelling technologies must be advanced to make it practical and convenient for consumers to use hydrogen as a fuel. Finally, the adoption of hydrogen-powered vehicles and hydrogen fuel cells must be encouraged.

Despite the potential benefits of a hydrogen economy, there are also some challenges that must be overcome. One of the main challenges is the cost of producing and distributing hydrogen, which is currently much higher than the cost of producing and distributing fossil fuels. Additionally, there are concerns about the safety of hydrogen fuel storage and transportation. These challenges must be addressed through research and development, as well as investment in new technologies, to bring the costs down and improve the safety of hydrogen as a fuel.

The market for hydrogen is currently growing and is estimated to be worth several billion dollars globally. However, it is still a relatively small market compared to the fossil fuel industry. In recent years, there has been increasing interest in hydrogen as an energy source, and as a result, investment in the development of hydrogen production, storage, and distribution technologies has increased. This has led to growth in the hydrogen market, with increasing demand for hydrogen fuel cells, hydrogen-powered vehicles, and other hydrogen-based technologies.

However, the current typical production of hydrogen from natural gas produces carbon dioxide as a by-product, which is a potent greenhouse gas and a contributor to climate change. Additionally, the extraction of natural gas from the ground can have negative impacts on local communities and ecosystems, as well as releasing methane, a potent greenhouse gas, into the atmosphere. Therefore, there is a growing interest in developing alternative sources of hydrogen, such as water electrolysis, which produce hydrogen that can be directly inserted without producing carbon dioxide. These technologies are becoming more cost-competitive and efficient, and are expected to play an increasingly important role in the production of hydrogen in the coming years.

Despite its relatively small size, the hydrogen market is expected to continue to grow in the coming years, as governments, especially in industrialized countries, around the world implement policies to promote the use of clean energy and reduce greenhouse gas emissions. The increasing availability of hydrogen production technologies, including the use of renewable energy sources to produce hydrogen, is also expected to drive growth in the hydrogen market. However, the growth of the market is likely to be uneven, with some regions experiencing faster growth than others.

2.1.1. Current Markets

Globally, the Hydrogen market was valued at USD 160 billion in 2021 [2], and is expected to grow at a 10% compounded annual growth rate between 2022 and 2028, reaching over USD 280 billion in 2028. Hydrogen demand increased from ~90 million tons kg in 2020 to ~95 million tons kg in 2021, recovering from a slight dip in 2020 due to the COVID-19 pandemic and surpassing 2019 demand levels [ii]. An overview of recent annual hydrogen demand, split by region, is shown in Figure 2.

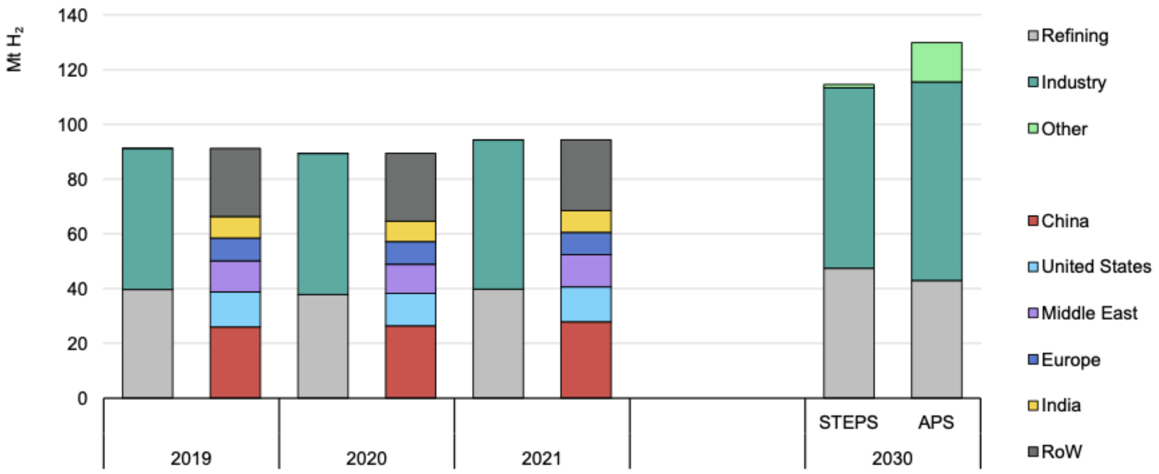

Figure 2, current and project hydrogen demand in million tons per year. STEPS = Stated Policies Scenario, APS = Announced Pledges Scenario, RoW = Rest of the World. Copyright 2022 IEA[ii], shared under a compatible licence.

Currently, hydrogen has many industrial applications, and is used as a raw material in the production of a variety of chemicals and other products. Some of the most common industrial applications of hydrogen include:

1. Ammonia production: Hydrogen is used in the production of ammonia, a key ingredient in the manufacture of fertilizers, as well as in the production of various chemicals and plastics.
2. Refining oil: Hydrogen is used in the refining of oil to remove impurities, such as sulfur and nitrogen. This helps to improve the quality of the refined products and reduce the environmental impact of the refining process.
3. Food processing: Food-grade hydrogen is used in the processing of various food products, such as chocolate and margarine.
4. Metallurgical processes: Hydrogen is used in various metallurgical processes, such as the production of steel and the refining of metals.
5. Hydrogenation: Hydrogen is used in the hydrogenation of oils and fats to produce products such as margarine and shortening.

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[2] Retrieved at 15-03-2023: https://finance.yahoo.com/news/hydrogen-generation-market-size-share-115900400.html

Most of the current hydrogen usage (90%) is for oil refining (50%) and nitrogen-based chemical fertilizer production (40%), mainly ammonia fertilizer [iii]. Fuel refining by-products provides feedstock for sulphur-based and phosphate-based chemical fertilizer. This makes hydrogen an important product for global food supply chains. Before the Russian invasion of Ukraine, natural gas as feedstock for hydrogen generation was accountable for around 75% of the operating cost for ammonia production. The energy crisis caused by Russia's war of aggression affects global food security by causing higher prices and lower availability of chemical fertilizers, on which almost half of global food supplies depend [3]. There is a direct relation between natural gas prices and ammonia prices, which were already at a high point before the Russian invasion [iv], an overview is provided in Figure 3.

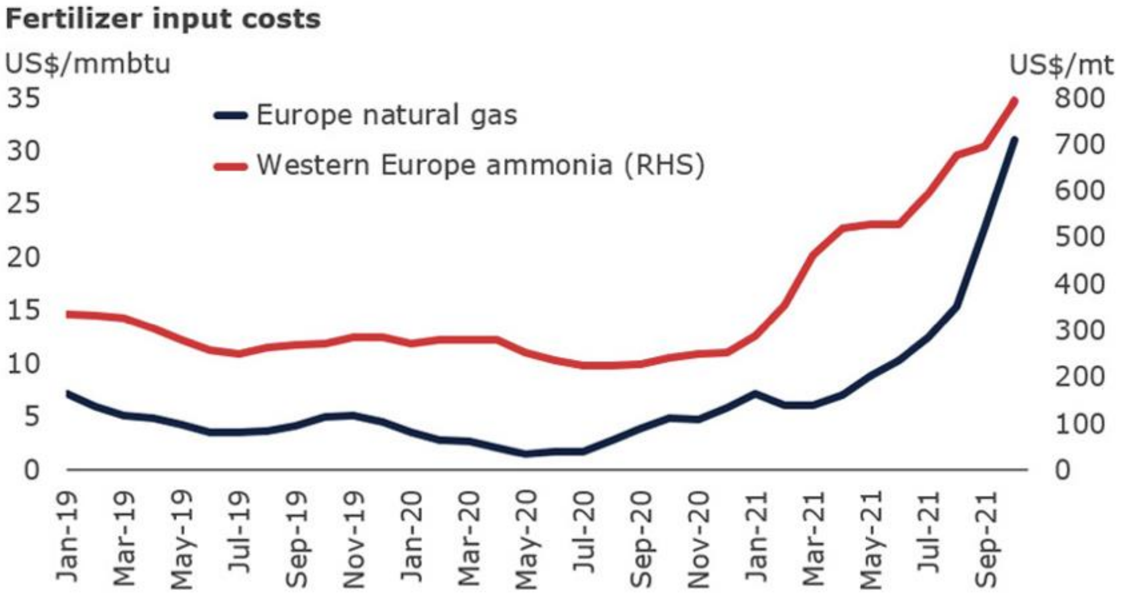

Figure 3, ammonia prices tend to close follow developments in natural gas prices. Copyright 2021 World Bank, shared under a compatible license.

2.1.1.1. Hydrogen for Ammonia Fertilizer

Hydrogen (H_2) is a key ingredient in the production of ammonia (NH_3) fertilizer, which is one of the most important industrial uses of hydrogen. The process of producing ammonia from hydrogen is known as the Haber-Bosch process [4], which was developed in the early 20th century.

The process begins by combining hydrogen and nitrogen from the air, which provides the required nitrogen (N_2), to produce ammonia. This reaction takes place under high pressure and high temperature, using a catalyst to facilitate the reaction. The ammonia produced in this reaction is then used as a feedstock in the production of fertilizer, as well as in the production of various chemicals and plastics.

One of the most common ways to produce hydrogen for this purpose is by using natural gas (typically methane, CH_4) as a feedstock. The process involves the steam reforming of natural gas, which is a process that converts natural gas into hydrogen and carbon dioxide. In the steam reforming process, natural gas is mixed with steam and heated to high temperatures, usually in the range of 700-1,000°C. This causes a chemical reaction to occur, in which the methane in

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[3] Retrieved on 15-03-2023: https://www.iea.org/commentaries/how-the-energy-crisis-is-exacerbating-the-food-crisis

[4] The Haber-Bosch process is considered one of the most important chemical processes ever invented and led to two separate noble prizes: https://www.britannica.com/technology/Haber-Bosch-process

the natural gas reacts with steam to produce hydrogen and carbon monoxide (CO). The carbon monoxide is then transformed into carbon dioxide (CO_2) which is not further used in the production of ammonia fertilizer. While there are a few variations possible in the exact production process, a typical process is modelled in Figure 4.

The use of natural gas as a feedstock for hydrogen production was considered attractive for a number of reasons, including the abundance of natural gas in many parts of the world and the relatively low cost of natural gas compared to other sources of hydrogen. Additionally, the steam reforming process is well established and has been used for many decades, making it a mature and reliable technology.

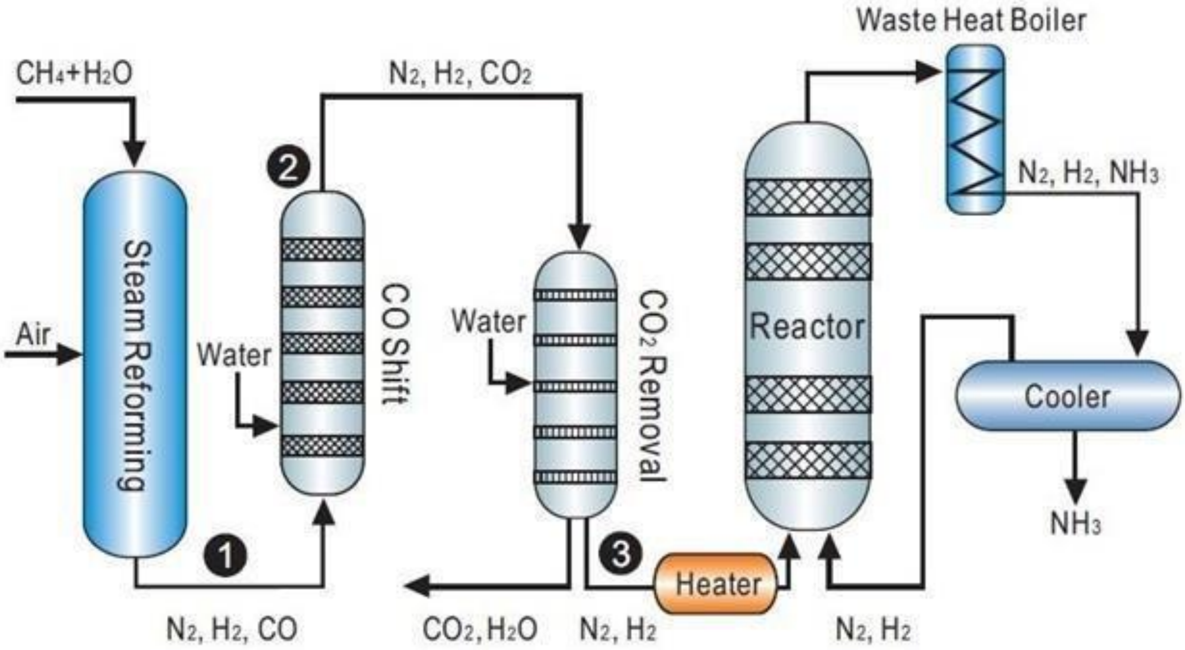
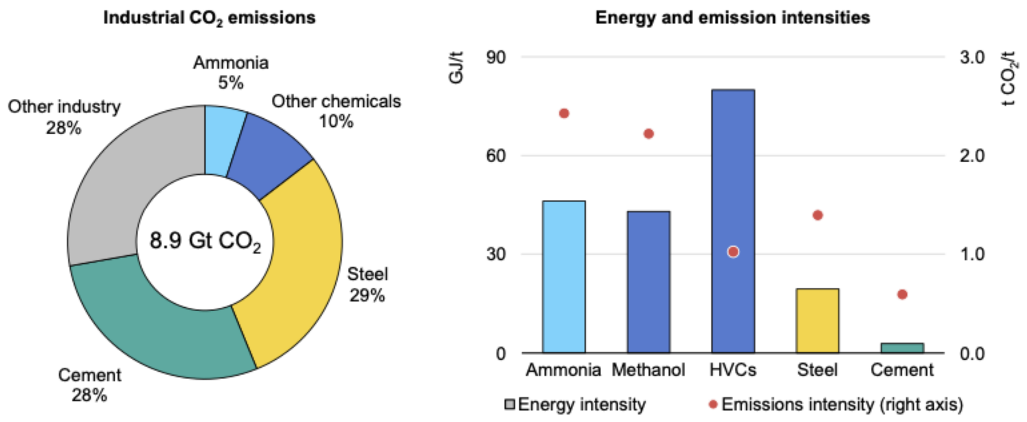


Figure 4, schematic overview of a typical ammonia production process from natural gas. Copyright 2017 Center for Promoting Ideas[v], shared with open access.

In 2020, ammonia production was responsible for roughly 2% of global energy use and 1.3% of CO_2 emissions. When looking at purely industrial CO2 emissions, ammonia accounts for 5% of emissions and no other chemical is responsible for as much CO2 emissions in its production as ammonia. Global ammonia production emissions are roughly similar to the CO2 emissions of Australia or South Africa. How ammonia production related emissions compare to other industrial emissions is shown in Figure 5.

According to Thyssenkrupp, half of the world's food production is reliant on mineral fertilizers, with ammonia being the most commonly used type [vi]. As depicted in Table 1, Russia ranks as one of the largest ammonia exporters, with only Saudi Arabia exporting more. In 2019, Ukraine was Russia's main export destination for ammonia. On the day of Russia’s large-scale invasion of Ukraine, exports of ammonia from Russia to and through Ukraine were mostly ceased by Russia, highlighting the world's significant dependence on a few countries with abundant natural gas resources for food security. By avoiding the prevalent approach of using natural gas as a feedstock, the production of clean hydrogen would not only contribute to a reduction in CO2 emissions but also offer an opportunity to broaden the hydrogen supply chain beyond undependable providers. This would result in an increase in economic resilience and food security.



IEA, 2021.

Figure 5, ammonia's share of industrial CO2 emissions and its emissions intensity. HVC = High Value chemicals. Copyright 2021 IEA [vii], shared under a compatible license.

Table 1, Major ammonia exporters in 2019, table adapted from data by the World Bank [viii].

Country	**Trade Value 1000USD**	**Quantity in KG**
Saudi Arabia	1,648,032.08	4,862,760,000
Russian Federation	1,114,021.03	4,647,650,000
Trinidad and Tobago	880,347.24	4,103,420,000
Indonesia	443,902.37	1,792,830,000
Canada	377,466.44	941,813,000
Netherlands	143,930.87	433,537,000
Malaysia	130,923.67	491,989,000
United States	96,826.32	421,371,000
Germany	93,212.37	
Egypt, Arab Rep.	90,211.56	158,599,000
United Kingdom	74,335.66	
Australia	73,270.45	305,504,000
France	37,594.13	129,376,000
Belgium	28,595.13	73,475,000
Bulgaria	25,943.32	67,113,200
Poland	22,738.08	73,849,300
Spain	22,424.37	72,135,900
Turkey	15,238.68	37,011,800
Korea, Rep.	12,115.28	15,225,000
Slovak Republic	9,552.28	30,759,800
Hungary	7,804.99	24,253,300
Croatia	7,474.89	22,384,000
Ukraine	5,432.62	23,289,600
Czech Republic	4,751.28	14,982,400
Japan	2,724.73	

2.1.1.2. Hydrogen for oil refining

Hydrogen is a critical element in the process of oil refining, particularly in the production of high-quality fuels such as gasoline, diesel, and aviation fuel. The use of hydrogen in refining offers numerous benefits such as higher yields, improved product quality, and a more efficient and sustainable refining process. Hydrogen is used for the removal of impurities such as sulfur, nitrogen, and metals from crude oil and its distillates. This process produces cleaner and more efficient fuels that meet increasingly stringent environmental regulations. Hydrogen is also used as a reactant and a catalyst to promote the chemical reactions that lead to the removal of impurities and the conversion of heavy fractions to lighter ones.

Hydrogen also allows refiners to increase the yield of valuable products such as gasoline, diesel, and aviation fuel, thereby enhancing their profitability. With the increasing focus on sustainability and the need to reduce greenhouse gas emissions, the use of hydrogen in oil refining is expected to become even more critical in the coming years. Reducing the sulphur content in fuels is crucial in the fight against ecological damage caused by acid rain. The presence of sulphur in fuels is a significant contributor to acid rain, and the use of hydrogen treatment in oil refining to remove sulphur is a crucial step in combating this environmental problem [ix].

Sulphur is a common by-product of oil refining with hydrogen. During this process, sulphur-containing compounds in the crude oil and its distillates are converted into hydrogen sulphide (H_2S) gas, which is then removed through a series of treatments. The H_2S is then treated to release the sulphur in the form of elemental sulphur or sulfuric acid. In some cases, the H_2S gas may also be sent to a Claus plant, which uses a series of chemical reactions to convert the H_2S gas into elemental sulphur. The resulting sulphur can then be processed and sold as a valuable by-product for use in a variety of industries, including agriculture and chemical production.

Sulphur for fertilizers

Overall, sulphur fertilizers are a critical component of modern agriculture, providing crops with the sulphur they need to grow and produce high yields. As agriculture continues to face new challenges, such as changing soil fertility and environmental pressures, the use of sulphur fertilizers is likely to become even more important in maintaining healthy plant growth and maximizing crop yields.

Sulphuric acid, often made from sulphur supplied by oil refineries, is a critical component in the production of phosphate fertilizers, playing an essential role in converting raw materials such as rock phosphate into more plant-available forms. Rock phosphate is a naturally occurring mineral that contains phosphorus, an essential nutrient for plant growth. However, the phosphorus in rock phosphate is not always readily available to plants, as it is often present in insoluble forms.

2.1.2. New Markets

Hydrogen is expected to have a significant role in various sectors in the future, as countries around the world aim to decarbonize their economies and reduce greenhouse gas emissions. Here are some of the big markets for hydrogen in the future:

1. Transportation: Hydrogen fuel cells are increasingly being used to power vehicles, particularly in the transportation sector. Hydrogen fuel cells are particularly suitable for heavy-duty vehicles such as trucks and buses, as they offer a longer driving range and faster refuelling times compared to battery-powered electric vehicles.

2. Industry: Hydrogen is expected to play a significant role in industrial processes such as steel production, chemical manufacturing, and refining. In these industries, hydrogen can be used as a feedstock, fuel, or reducing agent, enabling the production of these products with lower emissions.
3. Power generation: Hydrogen can be used in power generation through the use of fuel cells or combustion. In either case, hydrogen offers a clean and efficient alternative to fossil fuels, particularly in remote or off-grid areas where electricity generation can be challenging.
4. Buildings and heating: Hydrogen can be used in buildings and for heating purposes, particularly in areas where natural gas is not available. Hydrogen can be blended with natural gas or used in pure form in appliances such as boilers, furnaces, and water heaters.
5. Energy storage: Hydrogen is increasingly being considered as a potential energy storage solution, particularly in conjunction with intermittent renewable energy sources such as wind and solar. Hydrogen can be produced during periods of excess renewable energy, stored, and then used to generate electricity during times of high demand. Furthermore, hydrogen can be shipped over long distances with new technologies.

Overall, hydrogen is expected to have significant applications in various sectors in the future, offering a clean and efficient alternative to fossil fuels and helping to decarbonize economies around the world.

2.1.2.1. Transportation

Hydrogen is perhaps best known popularly for its potential in transportation. The concept of a fuel cell that produces electricity from a reaction between hydrogen and oxygen was first conceptualised and demonstrated in the first half of the 19th century. However, the first applications of fuel cells to power vehicles did not materialise until the second half of the 20th century. One early example is pictured in Figure 6. Though some vehicles successfully employed hydrogen as a fuel for internal combustion engines in the latter half of the 19th century [x].

Figure 6, the Chevrolet Electrovan was powered by fuel cell technology spun off by NASA's Moonshot programme, photo by John Lloyd (CC-BY 2.0).

Several hydrogen-fuelled cars have entered the market [5,6], but most car makers prioritise Battery Electric Vehicles (BEVs) over Fuel Cell Electric Vehicles (FCEVs). In the short term, until at least mid-2030s, BEV technology is expected to be more mature and easier to charge/refuel [xi]. FCEVs require hydrogen storage and currently have limited refuelling infrastructure in place. However, FCEVs are more competitive for Heavy-Duty Vehicles and specialised vehicles with high utilization rates. Commercial fuel cell-powered buses have been successfully trialled in Tokyo and other cities [7,8], and Toyota uses hydrogen fuel cell-powered forklifts in its European production facilities [9].

In auto racing, Toyota recently made some advances by using hydrogen in Internal Combustion Engine (ICE) powered racing cars. In 2021, Toyota participated in an endurance race in 2021[10], and in rally races in 2022 [11]. While hydrogen cars, both those powered by fuel cells and those with an internal combustion engine, rely on hydrogen as a gas, Toyota plans to test a liquid hydrogen powered car in an endurance race in 2023 [12]. Liquid hydrogen provides the benefit of having a superior energy density, but requires to be kept at a temperature of -253 to -259 celsius prohibiting its use.

Using hydrogen in ICEs is less efficient than in FCEVs but has advantages. ICEs can run on hydrogen with little modification, either exclusively or in a 'bi-fuel' setup and demonstration vehicles with bi-fuel technology have existed for some time[13]. Unlike FCEVs and BEVs, hydrogen fuelled ICE vehicles have a lower reliance on critical raw materials. The catalyser, a component found in most modern ICE cars to filter some exhaust fumes, would not be needed in hydrogen fuelled ICE vehicles. Employing hydrogen fuelled ICEs is considered a potential market for vehicles that see a low utilisation rate, where the majority of life-time emissions follow from the production and disposal phases as opposed to the use phase. E.G., for go-kart racing or small marine engines. For large marine engines, both fuel cell powered, and ICE powered engines are being developed though developments are far from mature.

2.1.2.2. Industry

Hydrogen fuel holds a great promise for industries that are hard to electrify, in so called hard-to-abate sectors [xii], [xiii]. These are industries/sectors that are seen as especially costly to decarbonize, typically because they involve processes for which no (commercially) viable alternative using electric power is available. Perhaps the most prominent of such industries is steel making. Certain chemical processes and manufacturing of certain building materials can be counted to this group as well. Typically, though not always, these industries currently rely on fossil fuels for chemical reactions that require a high heat.

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[5] Retrieved from Honda on 15-03-2023: https://hondanews.com/en-US/releases/release-9801c648f80e400084bf402d89eb091f-honda-fcv-concept-makes-world-debut-in-japan

[6] Retrieved from Toyota on 15-03-2023: https://www.toyota.com/mirai/

[7] Retrieved from the Tokyo Metropolitan Government on 15-03-2023: https://www.metro.tokyo.lg.jp/ENGLISH/TOPICS/2017/170224.htm

[8] Retrieved from the Hydrogen Fuel Cell Bus Council on 15-03-2023: https://www.hfcbuscouncil.com/news-resources

[9] Retrieved from Toyota on 15-03-2023: https://toyota-forklifts.eu/solutions/energy-solutions/what-fuel-cell-technology-means-for-your-forklift/

[10] Retrieved from Toyota Times on 15-03-2023: https://toyotatimes.jp/en/report/hpe_challenge_2021/150.html

[11] Retrieved from Toyota on 15-03-2023: https://global.toyota/en/newsroom/toyota/37888377.html

[12] Retrieved from Japan Times on 15-03-2023: https://www.japantimes.co.jp/news/2023/01/05/business/corporate-business/toyota-hydrogen-fuel-car/

[13] Retrieved from Mazda on 15-03-2023: https://www.mazda.com/contentassets/f1d0da18d8194242874915dda7b612d8/files/2006_no026.pdf

The iron and steel industry is a major source of CO_2 emissions worldwide. In Europe, the industry is responsible for 4% of CO_2 emissions, while globally, it is responsible for 9% of CO_2 emissions [xiv]. In Japan, the steel industry is responsible for 13% of the country's CO_2 emissions [xv]. When looking solely at industrial CO_2 emissions, steel making is responsible for roughly 30% of CO_2 emissions, as shown in Figure 5. In Japan steel making is responsible for roughly half of industrial CO_2 emissions. Much of these emissions come from energy-intensive processes that are hard to electrify.

The previously discussed chemical industries, fertilizer production and fuel refining, continue to play an important role in hydrogen demand till at least 2050 [iii]. The demand for chemical fertilizer is expected to grow by 30% between 2020 and 2030 alone, driven largely by global economic and population growth. The demand for hydrogen by the fuel refining industry is expected to at least grow in the coming years, partially driven by economic and population growth but also because of stricter environmental regulations. By 2050, it is likely that the fossil fuel refining industry has shrunk significantly though it is expected to still be a significant market according to the International Energy Agency.

2.1.2.3. Buildings and Heating

The use of hydrogen in residential and commercial buildings, outside of industrial processes, is not forecast to be a particularly large industry. Small-scale appliances such as heating for housing and offices or cooking, which currently run on fossil fuels like natural gas, are well suited for electrification. Nonetheless, governments, including Japan [14], and firms have experimented with supplying hydrogen to homes. Hydrogen in homes can be either combusted for heat [15], or used in in-house fuel cells that convert hydrogen to electricity [16]. Furthermore, recent advances have also been made in enabling the cooking of food through hydrogen-fuelled stoves [17]. One advantage is that some existing natural gas infrastructure, specifically the 'last-mile' to homes can be re-used with little modification where electrical grids might require a major upgrade to handle the heightened load from heating and cooking through electric appliances. Furthermore, it can be used in regions that lack both electric and natural gas infrastructure when hydrogen cannisters are used.

2.1.2.4. Power Generation

Burning hydrogen to create electricity is considered a sizeable potential market, though virtually non-existent as of now [xvi]. Thermal power stations can be designed to operate fully on hydrogen, in co-firing mode with a mixture of hydrogen and another fuel type or switch between fuels. In some cases, existing thermal power plants can be upgraded to work with hydrogen. Ammonia fuel, made from hydrogen and nitrogen, is often used in testing thermal power plants instead of pure hydrogen. Ammonia can be more easily transported and stored, and has a burning temperature more suitable for coal-powered plants. While not as energy-efficient as power generation through fuel cells, the existing infrastructure can largely be reused, and most of the technology is mature. Furthermore, thermal power plants that can switch between fuels and/or co-fire different fuel increase energy security as you are less reliant on the (steady) supply of a single fuel type.

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[14] Retrieved from The National News on 15-03-2023: https://www.thenationalnews.com/business/japans-plan-to-power-homes-with-hydrogen-faces-hurdles-1.171777

[15] Retrieved from Rinnai on 15-03-2023: https://www.rinnai.co.jp/en/releases/2022/0530/images/releases20220530_en.pdf

[16] Retrieved from Tokyo Gas on 15-03-2023: https://www.tokyo-gas.co.jp/Press_e/20110209-01e.pdf

[17] Retrieved from Japan Today on 15-03-2023: https://japantoday.com/category/tech/rinnai-toyota-start-exploring-hydrogen-powered-cooking-methods

As with most other uses of hydrogen, besides combustion in a thermal power plant, hydrogen can also provide electricity on a large scale through industrial fuel cells. While this method is more efficient than through combustion, the technology is not yet mature and relies on critical raw materials. Furthermore, such fuel cells generally require a high purity of hydrogen, while thermal power plants are more versatile when it comes to the hydrogen purity.

2.1.2.5. Hydrogen for Energy Storage

Hydrogen storage is a crucial component in the use of hydrogen as an energy carrier, and the development of efficient, cost-effective, and safe storage technologies is crucial for the widespread adoption of hydrogen as a low-carbon energy source. While hydrogen storage technologies have made significant progress, there are still challenges to be addressed, and ongoing research and development efforts are necessary to improve the performance, cost, and safety of hydrogen storage systems.

Compressed gas storage is the most common and well-established method for hydrogen storage. Hydrogen gas is stored at high pressure, typically between 350 and 700 bar, in high-pressure tanks made of carbon-fibre-reinforced polymer or steel. Compressed gas storage is relatively simple and cost-effective, but it requires significant energy for compression and can lead to large storage volumes.

Liquid hydrogen storage is another option for hydrogen storage. Liquid hydrogen is stored at extremely low temperatures (-253°C), and it requires cryogenic insulation and handling systems. Liquid hydrogen storage offers high energy density and is suitable for long-term storage, but it requires significant capital investment and energy for liquefaction.

Solid-state hydrogen storage is a newer technology that offers the potential for high storage densities and low-pressure storage. Solid-state storage materials, such as metal hydrides, can absorb and release hydrogen through reversible chemical reactions, making them suitable for hydrogen storage. However, solid-state storage materials are still in the early stages of development and face challenges such as slow hydrogen uptake and release rates, limited cycle life, and high cost.

Hydrogen storage can also be integrated with other energy storage systems, such as batteries or pumped hydro, to provide a more flexible and resilient energy storage solution. Hybrid systems that combine hydrogen storage with other storage technologies can help to address the challenges of intermittency and variability in renewable energy systems.

The optimal hydrogen storage method depends on the specific use case. For low-demand, short-term storage, a pressurised gas tank may be sufficient. For example, it can help a household with photovoltaic panels to have a stable electricity supply throughout the day. However, such low-demand, short-term cases tend to compete with electrochemical battery storage. While electrochemical battery storage tends to require more critical raw materials, hydrogen energy storage is currently more expensive and less efficient.

For applications with a larger energy demand or a need for long-term storage, electrochemical batteries may not be as effective. In these applications, a greater adoption of hydrogen for energy storage is projected. Some experts anticipate that energy-intensive industries, such as steel making, may invest in their own hydrogen storage as electricity supply increasingly relies on renewable energy with fluctuating prices and greater fluctuations between peak and low supply. Large energy traders might also invest in stockpiles near industrial parks, mimicking the current fossil fuel supply chain in this regard.

As an increased uptake in renewable energy might cause strong seasonal fluctuations in energy supply, it is expected that economies that heavily rely on hydrogen will stockpile national reserves. Similar to how Europe currently aims to fill its natural gas stockpiles before winter to cope with an increased energy demand for heating and transportation. With the transition towards both hydrogen and renewable energy, this might create a ‘double whammy’, as one expert put it, in that winters will see a low supply of renewable energy and a high demand of energy for heating and personal transportation. Though the intensity of this double whammy might be partially mitigated by improvements in the insulation of homes and offices, as well as through better public transport. Large underground salt caverns are currently studied for their ability to store large amounts of hydrogen at a low cost [18,19].

2.2. The Various Variations in Hydrogen Origin

This section of the background aims to provide a global overview of international hydrogen supply chains in the near future when Japan and the European Union (EU) begin to import hydrogen, ammonia, and hydrogen carriers.

To start, we will provide an overview of the various classifications of hydrogen. While hydrogen is essentially the same, distinctions can be made based on how it is produced, resulting in different types of classifications. There are several methods for categorising hydrogen, with one approach being to differentiate based on the production process and energy source or feedstock used. This method leads to the so-called "rainbow classification," which is shown in Table 2. It should be noted that there is no strict definition for each colour, and sometimes conflicting definitions can exist, Table 2 represents the most common definitions encountered throughout our research.

Table 2, classification of hydrogen by typical production process and feedstock / energy source. There is no set definition for every colour and at times conflicting definitions may exist.

Type of Hydrogen	**Typical production process**	**Description**
Brown	Methane steam reforming	Produced from lignite (brown) coal.
Black		Produced from bituminous (black) coal.
Grey		Produced from natural gas after steam reforming (most common) or other fossil fuels. This definition is also often used for hydrogen produced from brown or black coal and can be used for any fossil fuel based hydrogen.
Blue		Produced from fossil fuels (including coal or natural gas) but with carbon capture, utilization and/or storage.
Green / renewable	Electrolysis of water	Produced through electrolysis using renewable energy.
Purple/Pink		Produced through electrolysis using nuclear energy.
Yellow 1		Produced through electrolysis using a mixed grid supply.
Yellow 2		Produced solely through solar energy.

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[18] Retrieved on 15-03-2023: https://innovation.engie.com/en/articles/detail/hydrogen-underground-storage-salt-caverns/25906/general

[19] Retrieved on 15-03-2023: https://www.lindehydrogen.com/technology/hydrogen-storage

Turqouise	Other	Produced by thermal splitting methane.
White		Produced as a by-product of other industrial processes.

Another popular method of categorising hydrogen is based on its carbon intensity, distinguishing between low-carbon and high-carbon hydrogen. This classification uses a life cycle analysis to examine the total CO_2 equivalent greenhouse gas emissions per kilogram of hydrogen produced. The cut-off point between low-carbon and high-carbon hydrogen is often determined by policy makers. This categorisation is attractive to policy makers as they can adjust the cut-off point over time and gradually transition to lower carbon emissions. This method is technology-neutral but does favour certain ways of producing hydrogen.

Hydrogen produced using electrolysis, with power coming from renewable (green hydrogen) or nuclear energy (purple hydrogen), often falls below even the stricter cut-off points [20]. Hydrogen produced via a mixed-grid (yellow hydrogen) or through fossil fuels with carbon capture and storage technology (blue hydrogen) is not expected to be viable or cost-effective with strict cut-off points, but may be a viable and possibly cheaper option with higher cut-off points. Hydrogen produced from fossil fuel without any form of carbon capture is not commonly categorised as low-carbon hydrogen.

This classification can be sensitive to how greenhouse gas emissions are allocated to hydrogen production, particularly when hydrogen is produced as a by-product. For instance, when electrolysis is used to split water into oxygen and hydrogen, without proper regulation, the majority of life-cycle emissions could be allocated to the production of oxygen, resulting in the hydrogen being declared a low-carbon by-product.

The industrialised nations and the EU, who are expected to be the largest consumers of hydrogen, are still developing green taxonomies to support the decarbonisation of their economies as well as how the different types of hydrogen will be included. At present, blue hydrogen is expected to be the cheaper option for low-carbon hydrogen in most cases. However, green hydrogen is projected to become cost-competitive by 2030 and generally cheaper by 2050 as prices for renewable energy and electrolysers decrease over time [xvii].

The EU is currently inclined to favour hydrogen produced with electrolysers over blue hydrogen, but is still debating whether to equate green, purple, and mixed-energy grid derived hydrogen. The EU is open to using blue hydrogen as a transition fuel to improve its energy security by 2030. Japan tends to be more technology-neutral when it comes to low-carbon hydrogen and prioritises the role that hydrogen can play in its long-term energy security.

Overall, there is ongoing debate and development in the classification and use of low-carbon hydrogen, as different regions and countries have different priorities and approaches to achieving their decarbonisation goals. As the technology and economics of hydrogen production and storage continue to evolve, it is expected that the categorisation and use of low-carbon hydrogen will continue to evolve as well. However, as the transition to a hydrogen economy requires large investments, companies are increasingly demanding clarity and long-term stability from governments when it comes to classifications.

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[20] This is not guaranteed, however. Inefficiently produced renewable energy (e.g., using equipment with a low utilization rate) might have a high-carbon value as life-cycle emissions are considered. As the electrolysis process requires a lot of clean/pure water with current technology, the energy used to produce this water also has to be considered. If a water desalination process is used that relies on fossil fuels, you might get high-carbon green/purple hydrogen.

Typical considerations that governments have, in prioritizing which type of hydrogen production to pursue are:

- Amount of greenhouse gases emitted.
- Current advantages a country possesses, such as large fossil fuel reserves.
- The potential a country has for renewable energy.
- The availability of excess fresh water.
- Diversifying suppliers to increase resilience.
- Gaining an early competitive advantage in green hydrogen technology, which is projected to become dominant in the long-term.

2.2.1. Ammonia and Hydrogen Carriers

Although the previous classifications of hydrogen are all identical in their chemical composition, there are alternative compounds that consist mostly of hydrogen atoms and can serve as alternative energy carriers. The most well-known of these compounds is ammonia fuel.

Ammonia fuel is produced via the Haber-Bosch process, which involves reacting nitrogen and hydrogen gases under high pressure and temperature in the presence of a catalyst. The resulting ammonia is easily stored and transported, making it a potentially attractive alternative to pure hydrogen which can be more challenging and expensive to transport and store. Ammonia is a clean-burning fuel that produces no carbon emissions when combusted, and its burning point is comparable to that of coal. Ammonia is a viable fuel for co-firing with fossil fuels in thermal power plants, facilitating a transition away from fossil fuels that utilises existing infrastructure.

One major disadvantage of ammonia fuel, when compared to pure hydrogen, is that it requires more energy to produce. First, hydrogen must be produced, and then additional energy is needed to conduct the Haber-Bosch process to create ammonia. Furthermore, ammonia is not compatible with existing fuel cell technologies and must be converted back into pure hydrogen, which is another energy-intensive process.

Despite these limitations, Japan views ammonia as a promising method to import hydrogen over long distances. The Japanese government and firms are actively collaborating with partners in the Middle East, Africa, and Latin America to establish an ammonia fuel supply chain to Japan. Projections by the Hydrogen Council, as shown in Figure 7, show that seaborne ammonia transport will initially grow quicker than pure hydrogen transport [xviii].

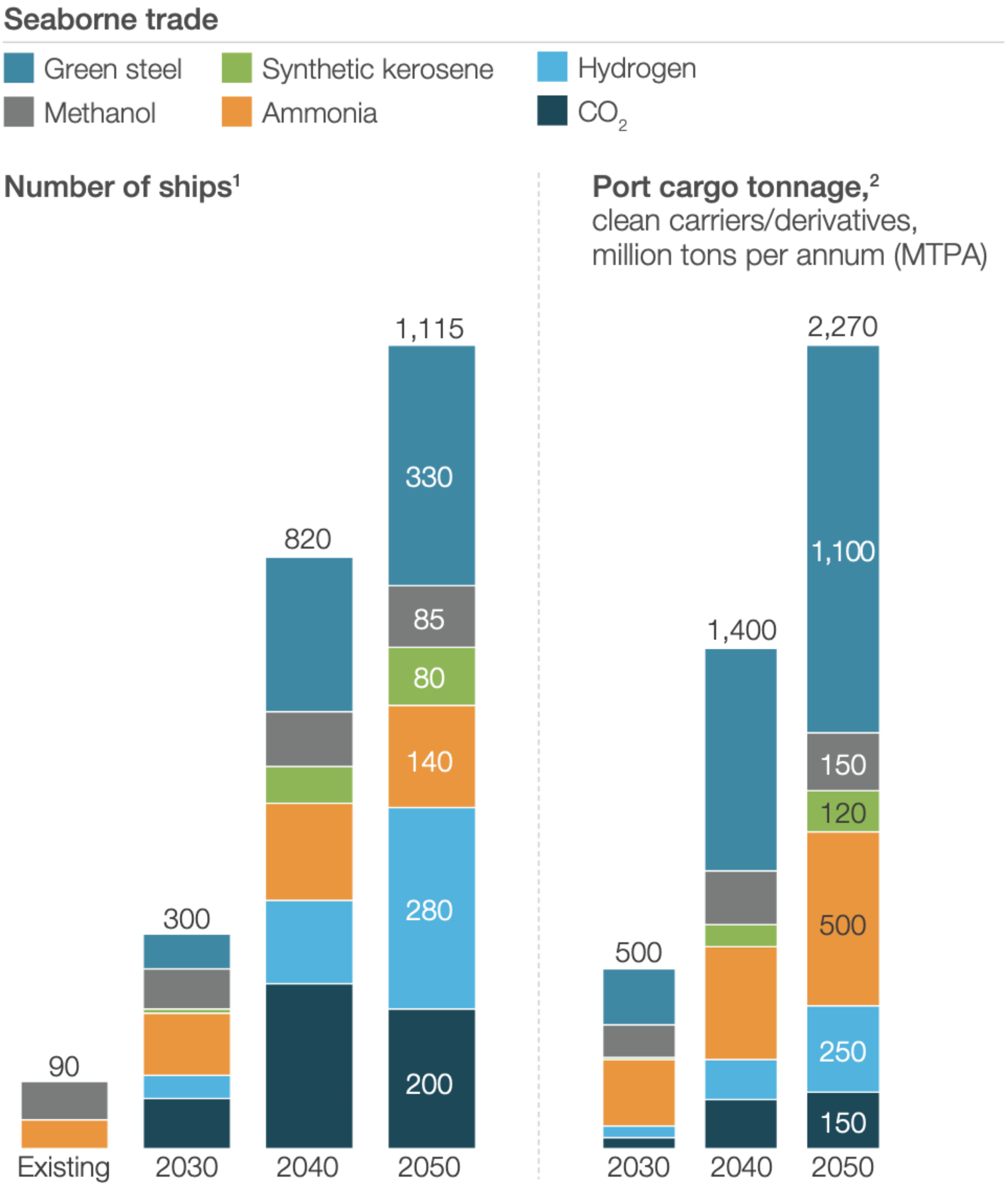

Figure 7, projected seaborne trade of Hydrogen, Ammonia, and other hydrogen related substances over the next decades [xviii]. *Copyright 2022 the Hydrogen Council, expression permission to reuse images in this publication granted.*

Liquid organic hydrogen carriers (LOHCs) are another method of transporting hydrogen. These carbon-containing compounds are enriched with hydrogen at the source, and the hydrogen is then extracted at the destination through a "dehydrogenation" process. The carrier in its hydrogen-poor state is then transported back to the source. Although there is currently limited direct use for such carriers, fuel cells that can consume them directly are theoretically possible. Burning an LOHC would result in greenhouse gas emissions and provide little benefit over burning fossil fuels, if any at all.

Japan has successfully transported LOHC fuel by ship from Brunei to Japan since 2020. However, Japan appears to be primarily focusing on pure hydrogen and ammonia.

2.3. Global Hydrogen Electrolyser Supply Chains

This section of the policy paper will provide more in-depth information on the supply chain needed to create the facilities for low-carbon hydrogen production using electrolysis. An often-overlooked part of supply chain resilience in a hydrogen economy. The ambitious plans currently outlined by the world's leading economies for scaling up hydrogen production will face severe material constraints. Renewable/green hydrogen production is expected to be mainly produced through the electrolysis of water. The more mature alkaline electrolysers require the Critical Raw Material (CRM) nickel. The more advanced Proton exchange membrane (PEM) electrolysers, as well as most hydrogen fuel cells for the transportation sector, require platinum group metals which are all CRMs, including very rare iridium.

2.3.1. Technological Overview

Electrolysis is the process of using electrical current to cause a chemical reaction in a substance, typically a liquid solution. Electrolysis can be used to produce hydrogen, a clean and sustainable fuel, from water by splitting water molecules into hydrogen and oxygen gas.

There are two main types of electrolysers currently on the market:

1. Alkaline electrolysers.
2. Proton exchange membrane (PEM) electrolysers.

Alkaline electrolysers are the oldest and most mature type of electrolysers. They use a strong alkaline solution, typically potassium hydroxide (KOH), as the electrolyte. The electrolyte conducts the electrical current between the two electrodes, which are usually made of nickel or steel. When an electrical current is passed through the electrolyte, hydrogen gas is produced at the cathode and oxygen gas is produced at the anode. The gases are then separated and collected.

One of the advantages of alkaline electrolysers is that they are very efficient at converting electrical energy into hydrogen gas. They also have a long lifespan, typically around 20 years. However, they require a high concentration of potassium hydroxide, which can be corrosive and difficult to handle. Additionally, alkaline electrolysers are sensitive to impurities and can only use pure water as the feedstock. Alkaline electrolysers also operate at higher temperatures and have a longer start-up time, making them less useful for intermittent operation, e.g., to cover a sudden peak in renewable energy supply.

PEM electrolysers, on the other hand, use a solid polymer membrane as the electrolyte. The membrane allows the passage of protons from the anode to the cathode, while preventing the mixing of hydrogen and oxygen gases. The electrodes in PEM electrolysers are usually made of platinum or other noble metals.

PEM electrolysers have several advantages over alkaline electrolysers. They are more efficient at converting electrical energy into hydrogen gas, with efficiency rates of up to 80%. They also operate at lower temperatures and pressures, which reduces the risk of corrosion and makes them more flexible in terms of operating conditions. New PEM electrolysers under development can also use a wide range of water sources as the feedstock, including seawater and wastewater.

However, PEM electrolysers are more expensive than alkaline electrolysers, mainly due to the cost of the noble metal catalysts used in the electrodes. They also have a shorter lifespan, typically around 10 years. PEM electrolysers are also more sensitive to impurities and require a higher level of maintenance to ensure the membrane remains intact.

Overall, both alkaline and PEM electrolysers have their advantages and disadvantages, and the choice of which type to use depends on the specific application and operating conditions.

Electrolysers and fuel cells are both electrochemical devices that involve the conversion of chemical energy into electrical energy and vice versa. In fact, the basic design of these devices is very similar, with both consisting of an anode, a cathode, and an electrolyte.

In an electrolyser, an electrical current is used to split water molecules into hydrogen and oxygen gas at the anode and cathode respectively. In a fuel cell, on the other hand, hydrogen gas is supplied to the anode and reacts with oxygen from the air at the cathode to produce electrical energy and water as a by-product. The main difference between these devices is the direction of the electrochemical reaction and the source of the reactants.

However, the similarity between electrolysers and fuel cells goes beyond their basic design. In fact, some electrolysers can also operate as fuel cells by reversing the direction of the electrochemical reaction. This means that they can use hydrogen gas as a fuel and produce electrical energy and water as by-products. Similarly, some fuel cells can also operate as electrolysers by applying an external voltage to the device and splitting water molecules into hydrogen and oxygen gas. This capability is known as reversible operation and is a key feature of some advanced fuel cell technologies, though they tend to be less efficient than electrolysers or fuel cells build for a single operation.

2.3.2. The Core Supply Chain

The electrolyser supply chain consists of various stages, starting from the production of raw materials to the deployment of the electrolysis system.

The raw materials for electrolysers include metals, such as steel, and polymers, such as the membrane used in proton exchange membrane (PEM) electrolysers. Electrolysers also typically rely on critical raw materials. Alkaline electrolysers require nickel and PEM electrolysers require platinum group metals (PGMs). These raw materials are typically sourced from mining and chemical companies.

Once the raw materials have been sourced, they are processed and assembled into various components of the electrolysis system, including the electrodes, membrane, and stack. Manufacturing can be carried out by specialized electrolyser manufacturers or integrated with other companies that produce related products, such as fuel cell systems.

Once the electrolysis system components have been delivered to the customer, they are installed and commissioned. This typically involves working with specialized service providers who are trained in the installation and maintenance of electrolysers.
After the electrolysis system has been installed, it is operated and maintained by the customer or a specialized service provider. This includes regular maintenance, such as replacing worn out components, monitoring system performance, and optimizing the operation of the system.

At the end of its useful life, the electrolysis system is decommissioned, and the components are recycled or disposed of. This may involve working with specialized recycling companies that can recover valuable metals and other materials from the system. Especially PEM electrolysers have a good recycling potential because of the PGMs used for this type of electrolysers.

Overall, the electrolyser supply chain is complex and involves multiple stages, including raw material sourcing & processing, manufacturing, distribution, installation, operation and maintenance, and end-of-life management.

2.3.2.1. *Critical Raw Materials*

The largest part of the critical raw materials needed in a decarbonised economy that relies on hydrogen is likely to come from the additional demand for renewable energy needed to produce hydrogen, more so than from the required electrolysers [xix]. If we look at a generic model of an electrolyser or fuel cell, we see a variety of critical raw materials and other materials with a supply risk, an overview of the most common critical raw materials is shown in Figure 8. The majority of critical raw materials used are considered to have a medium supply risk according to the European Union, copper and nickel which are not considered critical raw materials by the EU do have some limited supply risk, as is shown in Figure 9.

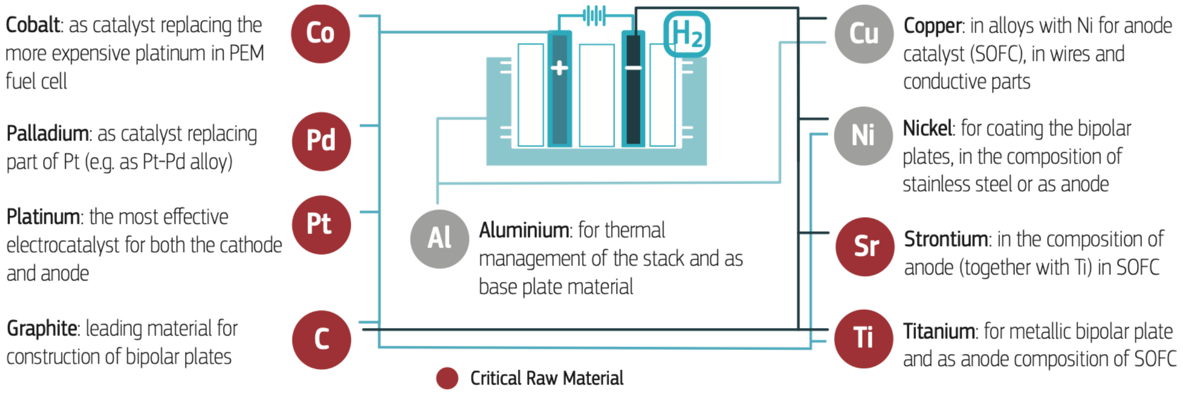

Figure 8, overview of critical raw materials typically used in electrolysers or fuel cells [xx]. Copyright 2020 European Union, shared under CC BY 4.0 license.

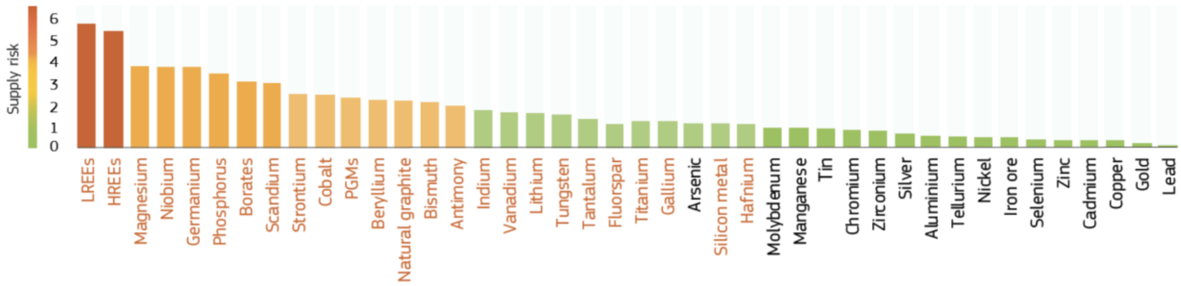

Figure 9, overview of the supply risk for a variety of critical raw materials in the EU [xx]. Copyright 2020 European Union, shared under CC BY 4.0 license.

It is expected that for most (critical) raw materials, the share of primary demand coming from the electrolyser market by 2050 will remain low [xix], as is shown in Figure 10. Notable exceptions are the PGMs Iridium and platinum of which the EU has no domestic primary reserves, only secondary reserves in primarily catalytic converters in exhaust systems and jewellery. Zinc and nickel are much more abundant but might pose some limited supply risks.

About half of the world's nickel reserves, and a quarter of the world's zinc reserves can be found in Southeast Asia and Australia. This provides a strong opportunity for especially Australia to provide a vertically integrated supply chain for (alkaline) electrolysers.

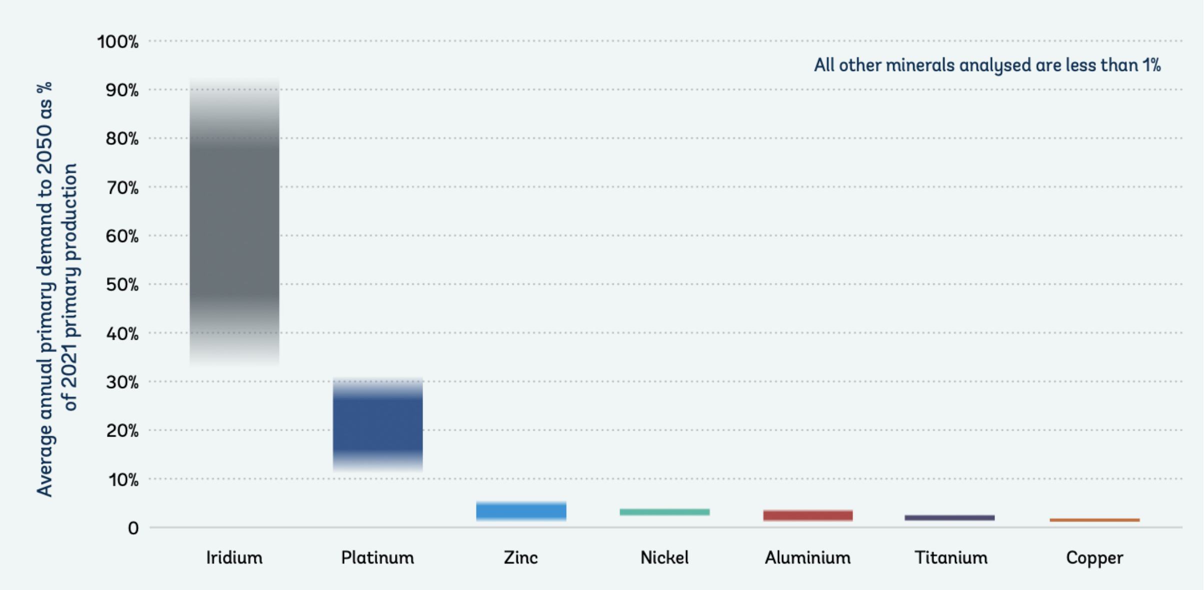

Figure 10, Projected average annual primary demand from hydrogen production and consumption to 2050 as a percentage of current primary production. Copyright 2022 by the Hydrogen council, expression permission to reuse images in this publication granted.

2.4. Hydrogen Diplomacy

Hydrogen diplomacy is a relatively new term used to describe the growing global interest in hydrogen as a clean and sustainable energy source, and the international efforts to promote cooperation and collaboration on hydrogen-related issues. Hydrogen diplomacy involves a range of activities, including bilateral and multilateral agreements on hydrogen research and development, technology transfer, and trade. It also involves collaboration on standards and regulations for the production, transport, and use of hydrogen, as well as joint efforts to promote the adoption of hydrogen technologies and infrastructure. The goal of hydrogen diplomacy is to create a global hydrogen economy that can help to address the urgent challenges of climate change and sustainable development while supporting a country's industrial interests.

In recent years, many countries have developed hydrogen strategies, but the majority lack a concrete roadmap. Among those that have a plan in place, there are three main groups:

- Industrialised countries that expect to require significant hydrogen imports.
- Industrialised countries that aim for self-sufficiency in hydrogen production.
- Countries that expect to become major hydrogen exporters.

The European Union is in a somewhat unique position, as projections indicate it will have a significant internal production and also rely heavily on imports, as illustrated in Figure 1. When studying recent diplomatic activity, the EU can be seen as similar to industrial countries such as Japan and South Korea, which anticipate significant hydrogen imports.

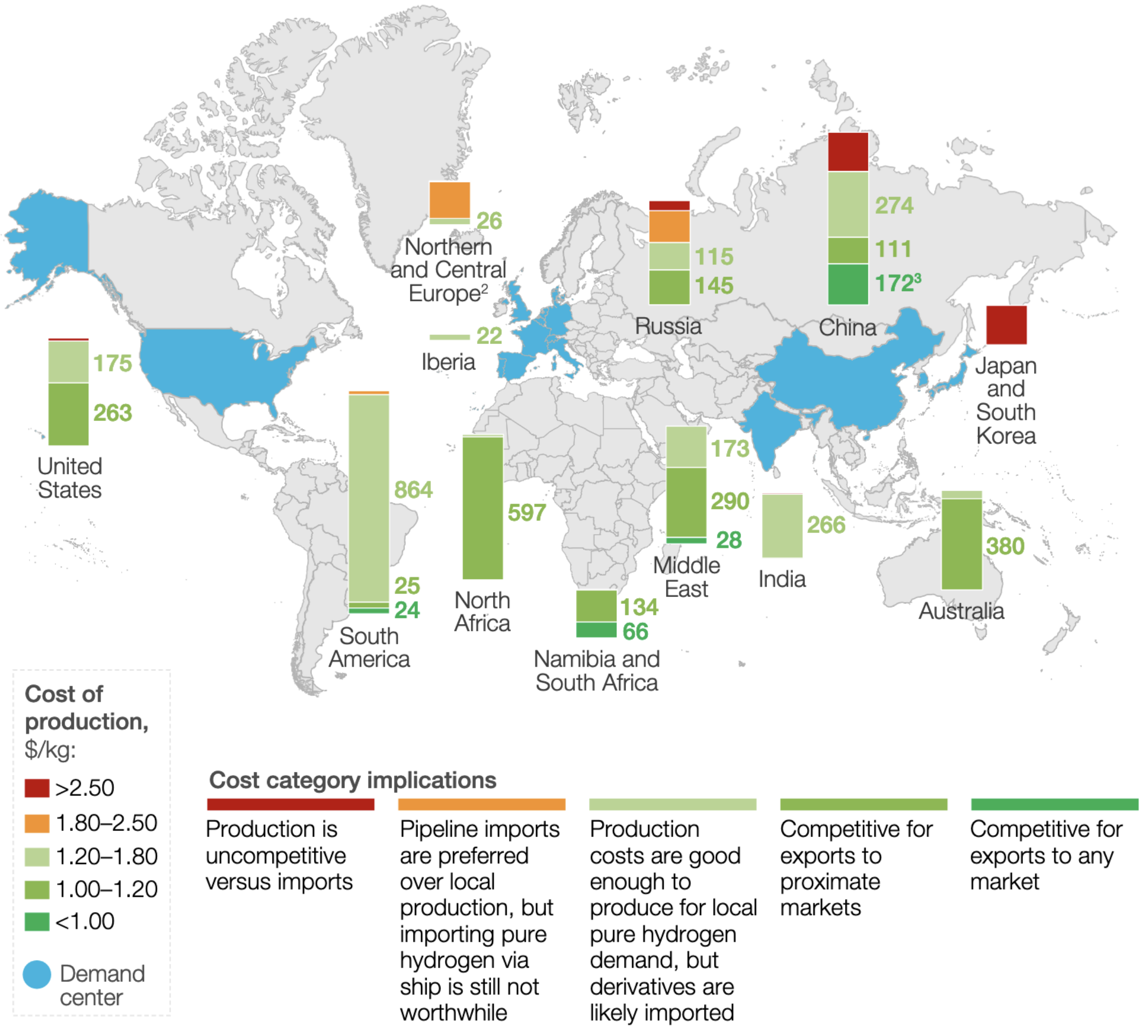

Figure 11, Hydrogen production potential for 2050 in million tons per year, split by cost of production. Copyright 2022 by the Hydrogen Council, expression permission to reuse images in this publication granted.

Figure 11 shows the hydrogen production potential for 2050 in million tons per year, split by cost of production for each region in the world. Japan's nearest reliable supplier of cheap hydrogen is Australia, and might face demand competition from South Korea, China, Southeast Asia, and India. Although it is expected that in time, China and India will increasingly be capable of supplying their own hydrogen needs.

2.4.1. Japan

As shown in Figure 1, Japan is expected to become a significant net importer of hydrogen, with very little domestic supply. Japan has also been the most active country in hydrogen diplomacy. The government agencies Japan Organization for Metals and Energy Security (JOGMEC) and the Japan International Cooperation Agency (JICA), as well as its ministries, notably the Ministry of Economy, Trade, and Industry (METI), are actively involved in promoting hydrogen diplomacy. Japan also supports its private sector to establish international hydrogen supply chains. Over the past year, numerous memorandums have been signed with public and private sector partners worldwide, including the EU.

Experts believe that in addition to securing a supply of hydrogen for Japan, the country hopes to export critical hydrogen technologies and strengthen its industrial sector through diplomacy. This is an essential component of many agreements signed with governments from other industrialised nations. Agreements with private sector partners and partners in non-industrialised regions, particularly in Southeast Asia, typically include a technology export component, as well as a financing component. Japan leverages its experience as the largest official development aid provider in Southeast Asia, which has historically focused a lot on economic and infrastructure projects.

A recent development is the development of the Asia Zero Emissions Community (AZEC), which was announced in 2022 and saw its first ministerial meeting in March 2023 [21]. AZEC is led by Japan and includes the majority of ASEAN nations (excluding Myanmar) and Australia. The formal purpose of AZEC is to accelerate "a clean, sustainable, just, affordable, and inclusive energy transition towards carbon neutrality/net-zero emissions in the Asian region." AZEC will serve as a robust platform to develop not only the hydrogen economy among its participating members, but also to aid in the development of renewable energy. Japan will provide technologies, financing, and take a leadership role in developing harmonised and interoperable standards for new decarbonisation technology employed in the region.

The domestic hydrogen market in Japan has been extensively described in the 2019 MINERVA report 'Hydrogen and fuel cells in Japan' by Jonathan Arias [22]. For recent hydrogen related foreign policy developments in Japan, please refer to Annex A.

2.4.2. Australia

Australia is projected to play a significant role in the emerging global hydrogen economy, due to its abundant renewable energy resources and strategic location in the Asia-Pacific region. As shown in Figure 1, might well become the world's largest exporter of hydrogen.

Australia is one of the world's largest exporters of coal and liquefied natural gas (LNG), but it is also rapidly developing its renewable energy sector. The country has abundant solar and wind resources, particularly in the northern and western regions, which could be used to produce low-cost renewable hydrogen through electrolysis. Australia also has significant reserves of natural gas, which can be used as a feedstock for blue hydrogen. In 2022, the first international shipment of liquid hydrogen was performed between Australia and Japan, based on blue hydrogen produced from brown coal[23].

Australia is well positioned to become a major exporter of hydrogen to countries in the Asia-Pacific region, particularly Japan, South Korea, and China, which are all investing heavily in hydrogen technologies and infrastructure. These countries are interested in importing low-carbon hydrogen to help them reduce their greenhouse gas emissions and meet their climate targets.

To support the growth of its hydrogen industry, Australia has launched a National Hydrogen Strategy, which sets out a roadmap for developing a domestic hydrogen industry and becoming

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[21] Retrieved on 15-03-2023: https://www.meti.go.jp/press/2022/03/20230306005/20230306005-24.pdf

[22] Retrieved from the EU-Japan Centre for Industrial Cooperation on 15-03-2023: https://www.eu-japan.eu/sites/default/files/publications/docs/hydrogen_and_fuel_cells_in_japan.pdf

[23] Retrieved from the Hydrogen Energy Supply Chain Project on 15-03-2023: https://www.hydrogenenergysupplychain.com/supply-chain/latrobe-valley/

a leading hydrogen exporter. The strategy includes measures to support research and development, demonstration projects, regulatory reform, and international cooperation.

Furthermore, Australia is currently the world's second-largest producer of nickel, with the majority of its nickel production exported to countries like China, Japan, and South Korea. The country has significant reserves of high-grade nickel deposits, particularly in Western Australia and Queensland, which are among the largest in the world.

Australia is a key partner in AZEC and projected to be the largest supplier of hydrogen and critical raw materials to decarbonize Japan and Southeast Asia.

2.4.3. ASEAN / Southeast Asia

Due to its strategic location, large population, and growing demand for clean energy.

Several countries in Southeast Asia, including Singapore, Indonesia, and Thailand, have already launched hydrogen initiatives and are investing in hydrogen production, storage, and transportation infrastructure. The region has abundant renewable energy potential, such as solar and wind power, as well as hydro, which could be used to produce low-cost renewable hydrogen through electrolysis. They also have growing demand for clean energy to support economic growth and reduce dependence on fossil fuels. Especially the development of new typhoon-proof wind turbines might be a game changer for the region.

In addition to its potential in the hydrogen economy, Southeast Asia is also a significant producer of critical raw materials like nickel, cobalt, and rare earth elements. Indonesia is one of the world's largest producers of nickel, which is a critical material for alkaline electrolysers, as well as for batteries. The country also has significant reserves of other critical materials, such as cobalt and rare earth elements, which are essential for the production of high-tech products like wind turbines. Indonesia has recently started to deploy policies to develop domestic nickel ore processing (a market which is currently dominated by China) and battery production [24,25], but has not yet issued similar plans for electrolysers production. Furthermore, The Philippines is also amongst the top 5 countries with the largest nickel reserves and might move to employ similar policies as Indonesia.

Southeast Asia's role in critical raw material mining is expected to grow in the coming years, as demand for these materials continues to increase in industries that are essential for the transition to a more sustainable and low-carbon economy. However, it is also important that mining and production of these materials are carried out in a responsible and sustainable manner, taking into account environmental and social considerations in order to retain access to western markets.

Japan sees Southeast Asia’s growing economies as a large market for hydrogen technology and is willing to provide financing towards establishing hydrogen supply chains in the region. AZEC is Japan’s diplomatic vehicle towards this purpose. While ASEAN nations have a good potential for renewable energy, due to their own developing energy requirements it might take a long time before the region will see much hydrogen exports. Though Brunei might be in a

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[24] Retrieved from the IEA on 15-03-2023: https://www.iea.org/policies/16084-prohibition-of-the-export-of-nickel-ore

[25] Retrieved from NBR on 15-03-2023: https://www.nbr.org/publication/indonesias-nickel-export-ban-impacts-on-supply-chains-and-the-energy-transition/

unique position to quickly become an exporter of blue hydrogen, and a hydrogen supply chain using liquid organic hydrogen carriers has already been established between Brunei and Japan.

2.4.4. Africa

Several countries in Africa, including Namibia, Morocco, Egypt, and South Africa, have already launched hydrogen initiatives and are investing in hydrogen production, storage, and transportation infrastructure. These countries have abundant renewable energy potential, such as solar and wind power, which could be used to produce low-cost renewable hydrogen through electrolysis. They also have growing demand for clean energy to support economic growth and reduce dependence on fossil fuels. North African countries like Egypt, Algeria, and Morocco can use their proximity to Europe to have relatively cheap hydrogen exports through pipelines, and have recently made plans for upgrading or starting gas pipeline to Europe that can be upgraded for hydrogen use in the future.

In addition to its potential in the hydrogen economy, Africa is also a significant producer of critical raw materials like cobalt and platinum group metals. These materials are essential for the production of high-tech products like electrolysers and batteries, as well as other advanced technologies. The Democratic Republic of Congo, for example, is one of the world's largest producers of cobalt, while South Africa is a major producer of platinum group metals.

As Africa is rather distant from Japan and does not already possess an advanced infrastructure to export energy to Japan, Japan is not likely to prioritize the development of hydrogen export infrastructure in Africa. However, Japan has a strong interest in the critical raw material reserves in Africa and might see Africa as a good market to sell its technology.

2.4.5. Arab Peninsula

Arabic countries also have the potential to become major hydrogen exporters, particularly to Asia, which is expected to be a major market for low-carbon hydrogen. The United Arab Emirates, for example, has already signed agreements to export hydrogen to Japan, while Saudi Arabia is developing a $5 billion green hydrogen plant to export hydrogen to Europe.

Japan has stable trade relations in the Arab gulf, where Japan sources much of its sizeable LNG imports. Japan is using these existing relations to develop joint projects for mainly blue ammonia exports, which is deemed as more suitable than pure hydrogen transport due to the long distance between the Arab peninsula and Japan.

2.4.6. United States

The United States has recently gained a renewed interest in hydrogen. While for a long time it was thought that the US would mainly look to build hydrogen production capacity to supply its domestic requirements, as was projected in Figure 1, since the Inflation Reduction Act was introduced things are set to change. The IRA is giving a major impetus to the development of a clean hydrogen economy in the United States. The US has now started developing mayor hubs for hydrogen exports and is keen to sign up Japan as a large initial client to scale up.

Since the shale gas revolution, the US has become a net energy exporter and has integrated this into its foreign policy. As the US seeks to establish more robust supply chains and decouple from China, it has implemented a foreign policy sometimes referred to as "friend-shoring." Providing energy security to friendly nations in their supply chains is increasingly critical, particularly in the wake of Russia's aggression, which has disrupted global energy markets.

Although the US currently provides energy security primarily in the form of liquefied natural gas (LNG), it intends to prepare for a future in which hydrogen replaces LNG.

When it comes to key technologies for a hydrogen supply chain, the US seems to be active on most fronts even though they might not always have the best technology on the market [xxi]. The US, like most other major economies, is likely to want to keep critical technologies for the hydrogen economy in-house.

2.4.7. China

China aims to become a leader of the hydrogen economy [xxii]. China already is the largest producer of hydrogen, mainly grey hydrogen. As hydrogen is expected to play an increasingly important role in fuelling industrial processes, China's demand for hydrogen will grow. China's approach to hydrogen is rather unique amongst major economies in that the initial focus is on increasing industrial hydrogen production capacity before any greening goals. Though ultimately, also China sees hydrogen as an important factor in decarbonising its economy. Multiple regions in China have very ambitious plans for becoming important players in the hydrogen economy, and regional plans can be far more ambitious than national government plans.

China already produces over half of global electrolyser capacity on an annual basis and is expected to greatly increase its electrolyser production capacity in the next five years [xxii,xxiii], as is shown in Figure 12. China falls behind western countries and Japan when it comes to how technological advanced its electrolysers are. However, China is able to produce alkaline electrolysers much cheaper than other countries, with some estimates suggestion that the cost per capacity for Chinese electrolysers is only half of that of competing electrolysers [xix,xxii]. It is expected that China might catch up with the technological frontier for hydrogen electrolysers in about 5 years.

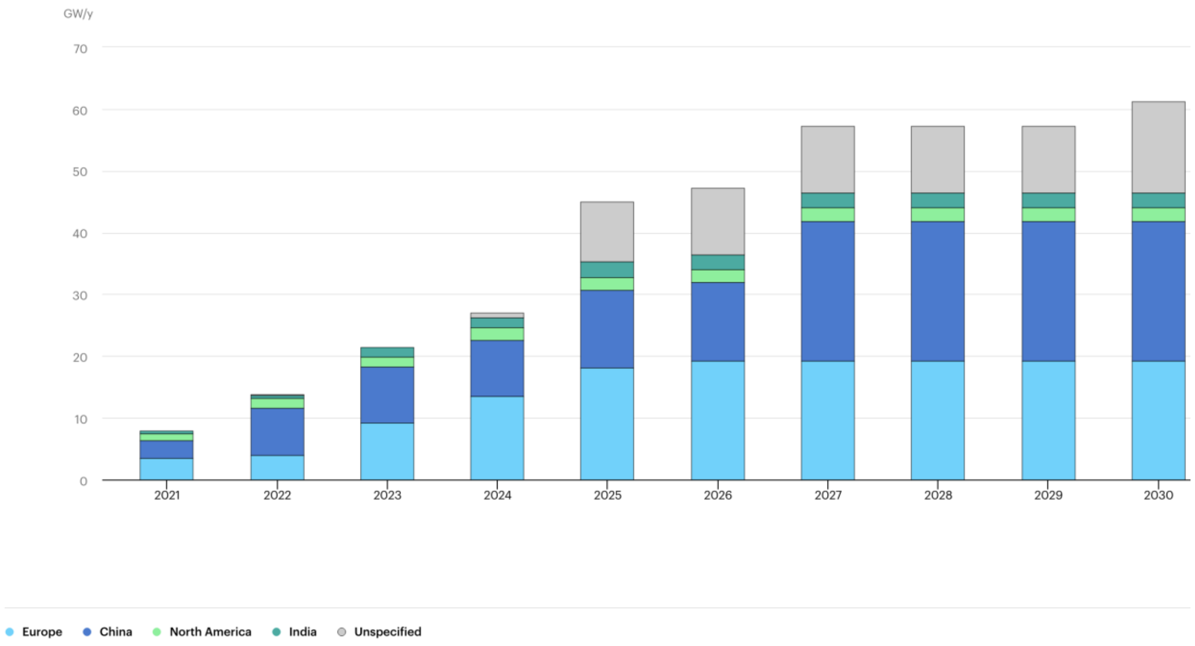

Figure 12, overview of current and projected annual electrolyser manufacturing capacity by region. Copyright 2022 IEA, shared under a CC BY 4.0 license.

Chinese concern for its energy security plays a leading role in the move to adopt green hydrogen. While China continues with their shale gas revolution, there is some concern that growth will soon stall [26]. However, the large potential for both cheap solar and cheap wind energy on the Tibetan Plateau and Inner Mongolia provides China with an opportunity to produce a large amount of hydrogen domestically. China shows little interest in becoming a hydrogen exporter and might even be a hydrogen importer during a transitional phase where it boosts domestic demand in an effort to kickstart hydrogen industries.

China is a significant player in the global supply of critical raw materials needed for the transition to clean energy, and it boasts one of the largest installed capacities for nickel processing.

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[26] Retrieved from Reuters on 15-03-2023: https://www.reuters.com/article/us-china-shalegas-idUSKBN29V0ZE

3. Recommendations for EU-Japan Cooperation

There are many areas in which the European Union and Japan could cooperate when it comes to establish a resilient hydrogen economy. Five key areas for cooperation can be identified:

1. Research and development: Both the EU and Japan are investing heavily in research and development of hydrogen technologies, including electrolysers and transport. Joint research and development projects could accelerate progress and help to overcome technical challenges.
2. Connectivity: Developing harmonized and interoperable standards & regulations is essential for the widespread adoption of hydrogen technologies. The EU and Japan could work together to develop such standards & regulations to ensure compatibility and interoperability between their respective hydrogen systems. Harmonised standards are relevant both domestically in Japan and the EU, and in third countries, to develop a more resilient global supply of hydrogen.
3. Infrastructure development: Building the necessary infrastructure for hydrogen production, storage, and transportation is a significant challenge. The EU and Japan could collaborate on developing and implementing infrastructure projects that can support the growth of the hydrogen economy.
4. Market development: As the hydrogen economy continues to grow, both the EU and Japan could work together to create new markets for hydrogen and encourage the adoption of hydrogen technologies in various sectors. An important market driver might be in sustainable finance.
5. Supply chain management: Ensuring a stable and secure supply of hydrogen is critical for the success of the hydrogen economy. The EU and Japan have to collaborate on managing the global supply chain for hydrogen as the two largest net importers, including the production, transportation, and storage of hydrogen, as well as the development of hydrogen trading platforms.

In December 2022, the European Commission and the Japanese government signed a Memorandum of cooperation on Hydrogen. The two parties share a recognition that renewable and low-carbon hydrogen is essential to achieving net-zero emissions. The memorandum aims to promote a sustainable and affordable production, trade, transport, storage, distribution, and use of renewable and low-carbon hydrogen, as well as a global rules-based and transparent hydrogen market. The agreement provides a framework for the development of detailed proposals for programs of cooperation, encouraging cooperation between governments, industry, and research agencies. Areas of cooperation include exchanging information and exploring coordination of hydrogen policies, regulations, incentivizing measures, and subsidies, and enhancing secure and rules-based international renewable and low-carbon hydrogen trade. The memorandum also aims for multilateral cooperation with third countries, in line with the EU-Japan Partnership on Sustainable Connectivity and Quality Infrastructure. The cooperation is expected to be implemented through various meetings, workshops, and events held periodically.

The memorandum is an important and crucial step in establishing a resilient hydrogen supply chain together. However, one important element that is lacking from the memorandum is cooperation in securing the required (critical) raw materials to establish sustainable hydrogen supply chains. By working together on both the technical and diplomatic fronts, the EU & Japan can ensure that the production and use of hydrogen is sustainable, environmentally responsible, and resilient.

A large number of the experts interviewed in making this report indicated how both Japan and the EU with its member states (Team Europe) consider having an in-house supply chain for hydrogen technology to be of high strategic importance. China already significantly undercuts Western and Japanese price points for alkaline electrolysers and has started exporting its products [xix,xxii]. The EU and Norway have launched two important Projects of Common European Interest (IPCEIs), enabling about 10 billion euros in state aid, to develop a complete clean hydrogen value chain. Japan is similarly supporting its industry. While the availability of significant amounts of government funding creates some opportunities, the protective nature of such measures might make it very difficult for European firms to enter the Japanese market, and vice versa, without possessing a very strong competitive advantage.

Both Team Europe and Japan want to avoid what happened to their solar panel industries. The European and Japanese solar panel industries suffered significant losses due to Chinese dumping practices. Chinese manufacturers flooded the global market with cheap solar panels, selling them at prices below the cost of production, and often receiving government subsidies to support their operations. This made it difficult for European and Japanese manufacturers to compete, leading to a significant decline in their market share. The European Union and Japan accused China of unfair trade practices and imposed anti-dumping duties on Chinese solar panels to protect their domestic industries. However, these measures were not enough to prevent the collapse of the European and Japanese solar panel industries. Many companies were forced to shut down or scale back their operations, leading to job losses and a decline in the development of renewable energy technologies in these regions. The Chinese dominance in the solar panel industry continued to grow, leading to concerns about the concentration of production in a single country and the impact on global supply chains. The collapse of the Japanese solar panel industry had a significant impact on the country's uptake of renewable energy.

3.1. Industrial Cooperation

3.1.1. Hydrogen Consumption Industries

While Team Europe and Japan are expected to be protective of strategic hydrogen production technology, they are likely to have a more relaxed approach to hydrogen consumption areas. Almost any technology that runs on fossil fuel can be "hydrogenated". While some products may be more likely to be electrified than hydrogenated, not all products can be easily electrified.

The shipbuilding industry, including both large and small ships, is a crucial sector in the transition towards decarbonisation. The EU currently heavily relies on Japan for small boat engines that run on fossil fuels, with Japan being a global market leader in this area. However, due to the large weight of batteries required for electrification, hydrogen or hydrogen-derived fuels are more likely to be used in this industry. Although less energy-efficient than fuel cell-powered electric engines, boats that see low usage may have a lower environmental life-cycle impact if they run on a hydrogen-fuelled combustion engine. Japanese companies such as Toyota and Mazda have some experience in developing hydrogen-fuelled combustion engines, which could be utilised in the marine sector.

The steelmaking industry is a critical sector in decarbonizing both the European and Japanese economies due to its significant CO_2 emissions. Japan is expected to prioritise the development of its own technology in this sector because steelmaking is crucial to Japan's economic security. However, favourable conditions in sustainable finance and carbon pricing mechanisms might encourage Japanese steelmaking companies to prioritize hydrogenation in their European subsidiaries.

3.1.2. (Expiring) Patents

Research into using hydrogen as a fuel has been ongoing for many decades, with many patents filed. However, as the hydrogen economy has not yet taken off, many patents have already expired or will expire soon without ever making it to the market. This provides unique opportunities for SMEs or start-ups that have a limited budget for their own R&D. New innovative ways, or a better market, might bring new value to old patents and create new business opportunities. Additive manufacturing saw a similar development, where the market gained a massive impetus when a few key patents expired after a lagged start of the industry.

Both the EU & Japan are leading in the number of hydrogen-related patents filed [27]. The EU & Japan have been consistently amongst the top 3 of patent filing regions since 2001, as shown in Figure 13. According to an expert, many of the older patents that are nearing expiration can be licensed at a relatively low cost, providing companies with an opportunity to gain a head start on technology that will soon be publicly available. This can be particularly beneficial for small and medium-sized enterprises (SMEs) that are trying to establish themselves in the market. The expiration of many patents may also serve as an impetus for new start-ups in the hydrogen sector. However, for European SMEs in particular, it might be hard to establish a business relation with Japanese paten holders and they made require services such as those offered by the EU-Japan Centre for Industrial Cooperation.

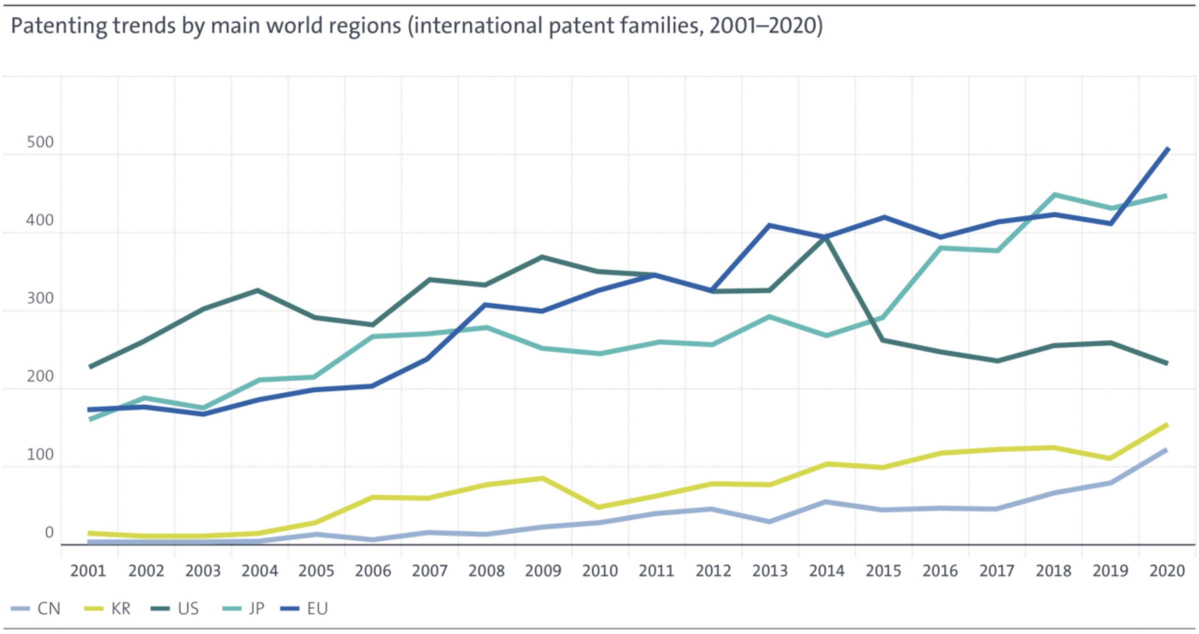

Figure 13, Patenting trends by main world regions in the area of hydrogen technology. Copyright 2023 the European Patent Office, allowed to be reused.

3.1.3. On-Shore Material Processing

On-shoring material processing capabilities refers to the process of bringing back or developing domestic production and processing of critical raw materials, rather than relying on overseas suppliers such as China. For Japan, a nation with limited natural resources and a strong

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[27] Retrieved from the European Patent Office on 15-03-2023: https://www.epo.org/news-events/news/2023/20230110.html

dependence on imports, securing critical raw material supply chains is of paramount importance. The onshoring of material processing capabilities can provide several strategic benefits for Japan:

1. Enhanced supply chain resilience: By developing domestic processing capabilities, Japan can reduce its reliance on overseas suppliers and minimise the risk of supply chain disruptions due to geopolitical tensions, trade disputes, or other unforeseen events. This resilience is particularly important the hydrogen economy, but also for other industries that are vital to Japan's economy, such as automotive, electronics, and renewable energy.

2. Strengthened national security: Critical raw materials, such as rare earth elements, are essential for the production of advanced technologies used in various industries, including defence and aerospace. On-shoring material processing capabilities can help ensure a stable supply of these strategic resources, contributing to Japan's national security and technological leadership.

3. Economic growth and job creation: Developing domestic processing facilities can lead to economic growth and job creation within Japan. By investing in on-shoring initiatives, the country can stimulate its industrial sector, create new employment opportunities, and foster the development of skilled labour in the field of material processing.

4. Improved environmental and labour standards: On-shoring material processing capabilities can enable Japan to exert greater control over the environmental and labour standards associated with the production and processing of critical raw materials. This can help reduce the negative environmental impacts and unethical labour practices often associated with overseas mining and processing operations.

5. Increased innovation and technological advancement: By fostering a domestic ecosystem for material processing, Japan can drive innovation and technological advancements in the field. This can lead to the development of new, more efficient, and sustainable methods for processing critical raw materials, ultimately contributing to Japan's global competitiveness.

6. Fostering strategic partnerships and regional cooperation: Although on-shoring aims to develop domestic capabilities, it can also lead to the establishment of strategic partnerships and regional cooperation. By working with neighbouring countries that possess critical raw materials, Japan can strengthen regional supply chains, promote resource-sharing, and reduce dependency on distant suppliers.

By developing domestic processing facilities and reducing reliance on overseas suppliers, Japan can enhance supply chain resilience, strengthen national security, promote economic growth, and foster innovation. Additionally, on-shoring can help improve environmental and labour standards associated with material processing, and encourage strategic partnerships and regional cooperation.

Experts suggest that Japan is likely to welcome European companies that can bring their expertise and assist in developing Japan’s material processing capabilities. Additionally, Japan may also welcome joint research and development efforts aimed at enhancing these processing capabilities. Finally, Europe’s growing sustainable finance market may also play a potential role in this regard. Japan could be more competitive than other nations in the region in many ESG (Environmental, Social, and corporate Governance) topics, whereas material processing tends to be an industry with significant adverse environmental and social impacts.

3.1.4. Recycling

Large-scale industrial electrolyzers may contain significant amounts of metals and other materials that could be recycled. Recycling of electrolyzers is still in its early stages, and there are limited facilities for the recycling of these devices. However, as the use of electrolyzers grows and their lifetimes shorten due to technological advancements, there is an increasing need for the recycling of these devices. Some companies are already exploring ways to recycle electrolyzers, and several research projects are underway to develop more efficient and cost-effective methods for the recycling of these devices.

The need for recycling is significant for platinum group metals (PGMs), which are mainly used in PEM electrolysers, as the projected annual production capacity for these metals will not cover the forecasted demand [xxiv]. Recycling PGMs from old electrolyser stacks for use in new stacks will be crucial to ensure there are enough of these metals available [xxv]. While efficient recycling of electrolysers can provide a valuable solution to a low supply of raw PGMs, the fact that PEM electrolysers have an expected lifetime of 7-20 years (pending forecasted improvements in the technology) will not make recycling an effective solution in the early scale-up phase of a green hydrogen economy.

However, steps can be taken to improve the recycling rate of PGMs recovered from other industries. Currently, the majority of imported PGMs in Japan are used for the production of catalytic converters in car exhausts [xxvi]. The European Union currently leads the world in employing PGMs in exhaust catalysts, due to the Union’s strict regulations to limit exhaust fumes, and in the recycling of said catalysts [xxvii]. When European firms export their know-how, it would benefit both the EU and Japan, as there would be less competition for primary materials. It must be said that the recycling rate in Japan is not far behind that in Europe, and Japanese firms might hold technology that is equally interesting for the EU. Large gains can also be made worldwide if the EU and Japan cooperate to aid developing nations in setting up full supply chains for recycling cars. Developing countries often have informal recycling chains that lack the sophisticated technology to recover PGMs, despite the profitability of recycling these metals.

As the sale of cars with internal combustion engines, and thus the need for catalytic converters, might recede with the advent of battery & fuel cell electric vehicles, the demand for PGMs for exhaust systems will lower and recyclers might look to build new customer relations with electrolyser & fuel cell producers outside of the traditional automobile industry.

3.1.5. Renewable Energy

As green hydrogen is expected to become an increasingly large part of the hydrogen mix, hydrogen will cause an increased demand for renewable energy. Japan has strong capabilities for advanced solar power technology and relies on imports from China for its cheaper solar power. However, European firms can play a significant role in increasing Japan's capacity for wind energy. It is foreseen that there will be an especially large opportunity for floating offshore wind power. Currently, wind power accounts for less than 1% of Japan's power supply, even though total renewable energy supplies provide over 20% of Japan's electricity [28]. Japan aims to have renewables account for 36-38% of its electricity supply by 2030. It was only as recent as December 2022 that Japan saw its first large offshore wind farm open, with 20 turbines by Danish Vestas [29]. A growth in domestic green hydrogen production will directly impact the demand for domestic green power.

3.2. Trilateral & Multilateral Cooperation

Considering that Japan is likely to rely on imports for the majority of its future hydrogen supply, as shown in Figure 1, there will be ample opportunity for industrial cooperation outside of Japan when it comes to hydrogen production and infrastructure. As technology leaders and large industrialised parties, Japan and the EU can collaborate on hydrogen developments in almost every corner of the world. However, during our research, we identified two broad regions that are of special interest to the EU and Japan when it comes to the hydrogen economy.

First, we will highlight opportunities for cooperation in ASEAN and with Australia. Australia and ASEAN, together with Japan, make up the Asian Zero Emissions Community (AZEC). Due to its relatively close proximity to Japan, and Japan's strong historic trade and investment experience with this region, this region is considered one of the most important for Japan's hydrogen economy. Though, due to the greater distance, this region is unlikely to provide a large share of Europe's hydrogen imports.

Second, we will highlight opportunities for cooperation in Africa and the Middle East. Here the roles are reversed, and these regions are likely to provide a large share of the EU's hydrogen imports but will likely provide less of Japan's hydrogen imports. Nonetheless, Japan is also actively engaged with nations and firms in this part of the world to establish hydrogen supply chains, although Japan is mainly invested in ammonia trade with this region. Furthermore, Japan takes a strong interest in Africa for its critical raw material reserves necessary to establish a hydrogen economy.

3.2.1. ASEAN & Australia, the Asian Zero Emissions Community

As mentioned earlier, the Asian Zero Emissions Community (AZEC) countries are important partners for Japan in their shift to a hydrogen economy. Not only do some of these countries have the potential to export hydrogen to Japan, due to their relative proximity and high renewable energy potential, but also because Japan has a long history of investing and trading with these countries, dating back to the 1950s [30]. Japan has invested especially in the areas of infrastructure and power generation, providing a wealth of relevant experience for hydrogen related investments in the region. European firms can use Japan’s extensive knowledge on doing business in the ASEAN member states to lower the risk of investing in the region.

Australia is quite different from ASEAN states but is nonetheless intrinsically linked to the region as a close neighbour and one of the region's major energy providers. Japan is Australia’s largest energy exports destination [31]. Japan is looking to build on this existing relationship and

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[28] Retrieved on 15-03-2023: https://www.japantimes.co.jp/news/2022/11/25/business/renewables-electricity-share-fiscal-2021/

[29] Retrieved on 15-03-2023: https://asia.nikkei.com/Business/Energy/Japan-s-first-big-offshore-wind-farm-begins-operation

[30] Retrieved on 15-03-2023: https://www.jica.go.jp/english/publications/j-world/c8h0vm000082pnre-att/1309_05.pdf

[31] Retrieved on 15-03-2023: https://www.eia.gov/international/analysis/country/AUS

is invested in Australia becoming one of its chief hydrogen suppliers. It is not likely that ASEAN nations, outside of Brunei and Malaysia who are already exporting significant amounts of fossil fuel products, will soon become significant energy exporters, and part of the plans behind AZEC is to have Australia export hydrogen to the ASEAN participants as well. While this might seem to go against Japan's interest in securing hydrogen for itself, Japan aims to export its advanced hydrogen technology to other AZEC nations and to provide the finance, including with a new green transition bond market.

3.2.1.1. Harmonisation of Regulations and Standards

While hydrogen itself requires little regulation or standard setting outside of perhaps purity, there is a lot to be done to ensure connectivity in almost every other aspect. Countries need to collaborate on the development of common technical standards and protocols for hydrogen production, distribution, and utilisation. This can help ensure the interoperability of hydrogen technologies and infrastructure, enabling a more seamless integration of hydrogen into the global energy system. This can be initiated by both the public and private sector, but it is crucial that such standards are in place for the hydrogen economy to take off. Experts indicate that a lack of clarity on certain aspects, such as when hydrogen can be classified as renewable or low-carbon, can impede large private-sector investments in hydrogen.

With Japan's leading role in experimental seaborne hydrogen transport, Japan is in a strong position to develop international hydrogen-related standards and regulations. Japan is expected to push its connectivity standards in the AZEC region to both ensure its energy security and to allow its hydrogen industry to scale up. Considering that the European Union and Japan both have a strong interest in a resilient and diverse global supply of hydrogen in the future, it is seen as in the interest of both to have compatible standards.

Both physical connectivity and digital connectivity need to be considered. Physical connectivity can manifest itself in port infrastructure, pressure used in storage, and purity of hydrogen. Good physical connectivity between regions will allow for both better economies of scale and the creation of more diverse and resilient supply chains. Digital connectivity can manifest itself in issues such as tracking the origins of a hydrogen mix, especially how it was produced, and the CO2 equivalent emissions and other environmental & social impacts resulting from the production and transport of hydrogen. How hydrogen is produced and transported is of increasing importance to parties in Europe due to upcoming regulation on corporate sustainability reporting, as well as for the upcoming carbon border adjustment mechanism. A good digital connectivity in these areas will enable more financing options for building global hydrogen supply chains. This affects both direct hydrogen/ammonia exports to the EU, as well as Japanese exports to the EU of products produced with hydrogen, either directly or indirectly.

3.2.1.2. Infrastructure Development

There might be good opportunities for European firms to become part of infrastructure development in AZEC. Especially in areas where the EU has technological superiority, there is a good chance of success. Japanese investments in third countries are expected to be more open to foreign firms than within Japan. Outside of direct participation in projects for hydrogen production, transportation, and utilisation, there are opportunities in the raw material mining and processing markets. This region holds about half of the world's nickel reserves [xxviii], a material that is crucial for alkaline electrolysers, while both Japan and the EU hold very little nickel reserves. Indonesia (22% of global nickel reserves) has become very protective of its material processing industry, and the Philippines (6% of global nickel reserves) might follow a similar path, providing an incentive to invest in nickel processing facilities in these countries. Australia (22% of global nickel reserves) is more open to exporting unprocessed nickel-containing ore. Historically, China was dominant in nickel processing, but Indonesia has successfully challenged China's position in this market in recent years.

3.2.1.3. Technology Export

As mentioned earlier, there will be an opportunity for European technology exports in Southeast Asia and Australia due to Japanese activity in the region. Europe is especially strong in the area of high-tech electrolysers and thus might have a good chance at exporting their electrolyser technology. Furthermore, Europe can provide some unique solutions for hydrogen storage and transportation. As shown in Figure 13, Japan and Europe are both leaders in the number of hydrogen-related patents filed. To have a highly advanced hydrogen supply chain will most likely involve both European and Japanese technology. As Europe develops a larger internal demand for hydrogen, European firms might also acquire economies of scale benefits earlier than Japanese firms and might be able to capitalise on this more and more as time goes on.

3.2.1.4. Finance

Japanese firms seeking to expand their hydrogen activities into Southeast Asia and/or Australia might turn towards European financial markets. Especially green hydrogen related investments could benefit from Europe's dominant position in the market for sustainable finance [xxix], as shown in Figure 14.

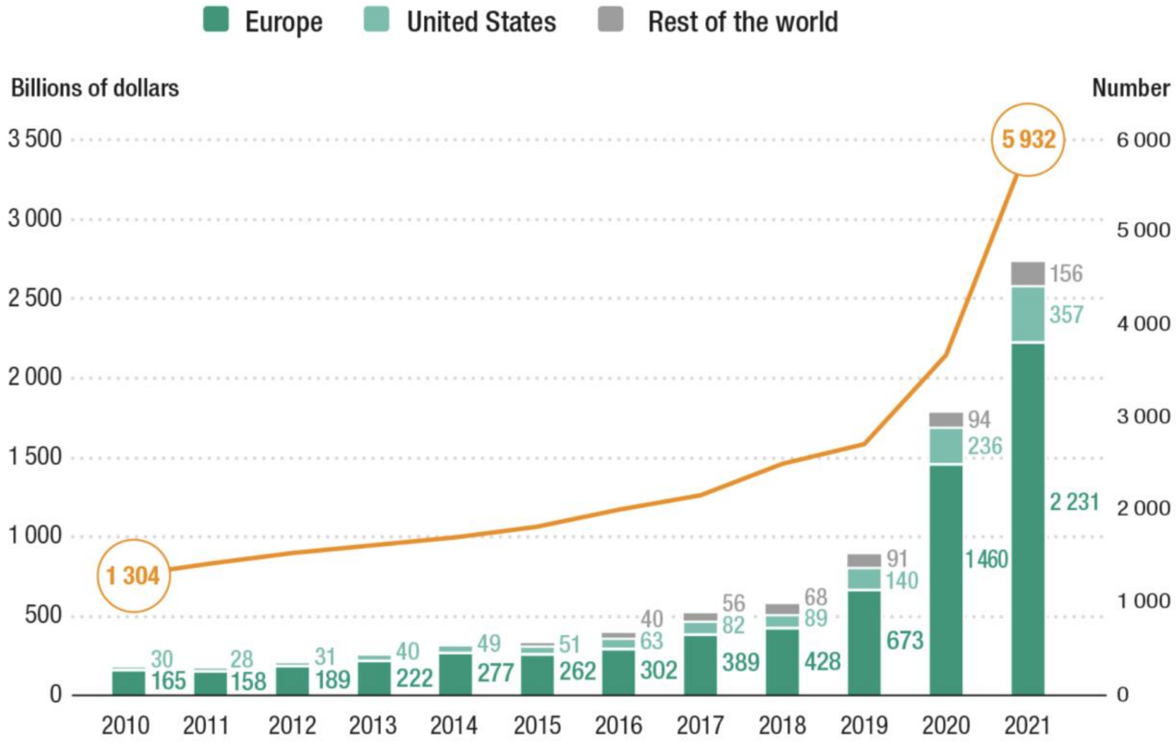

Figure 14, sustainable funds and assets under management divided by region (billions of dollars and numbers), copyright 2022 by UNCTAD, shared under a compatible license.

3.2.1.5. Renewable Energy

Wherever a hydrogen export infrastructure is developed, there might be opportunities to develop renewable energy farms. As Japan is aiming to develop a significant seaborn export capacity in the region, it might provide opportunities to invest in renewable energy production near hydrogen trading ports. Even if initial investments by Japan are aimed at blue or grey hydrogen production that does not rely on renewable energy, it is likely that ports with a good potential to scale up their hydrogen exports will be chosen. Especially South Vietnam, the Northern Philippines, and much of Australia have significant potential for offshore wind farms [32]. However, in some of these regions, new developments in typhoon-proof floating wind turbines might need to be further developed in order to tap the full wind power potential.

3.2.2. Africa and the Middle East

Opportunities for trilateral cooperation in Africa and the Middle East are similar to those in Southeast Asia and Australia, with the distinction that there is likely to be less industrial demand for hydrogen imports in Africa or the Middle East. These regions will mostly be hydrogen export-focused.

All Arab Gulf states are in a good position to export grey and/or blue hydrogen, owing to their large fossil fuel reserves, though only Saudi Arabia and Oman have strong potential for green hydrogen. While nearby Iraq also has strong potential for (green) hydrogen production based on its natural resources, the political instability in Iraq impedes investments in the country. Many countries in the Middle East lack the required freshwater supply for a large green hydrogen industry. Due to the considerable distance from Japan, Japan is likely to invest in infrastructure for ammonia exports over pure hydrogen exports.

Africa can be subdivided into several regions, though the largest divide from an EU perspective is between North Africa and Sub-Saharan Africa. North Africa's close proximity to Europe enables the opportunity for an international network of hydrogen pipelines, whereas Sub-Saharan Africa is more likely to export hydrogen to Europe by ship.

3.2.2.1. Connectivity

As with Southeast Asia and Australia, both the EU and Japan are likely to benefit from good connectivity. It should be noted that standards used for potential hydrogen pipeline connections between Europe and North Africa are of little relevance to Japan. However, if there is good connectivity for shipping hydrogen, this creates more diverse global supply chains and increases resilience for Japan and the EU. As shown in Figure 11, Africa and the Middle East are expected to provide much of the world's cheapest hydrogen by 2050 and are thus still interesting for long distance exports to Japan.

In fact, it is expected that the Middle East will export more hydrogen & ammonia to Japan than to Europe by 2030 and that little hydrogen will be exported from Africa at this point [xviii], as shown in Figure 15. Although by 2030, the Middle East, North Africa, and the south of Africa might be capable of diverting hydrogen exports to Europe if alternative supplies do not work as well as expected. By 2050, Europe will likely get much of its supplies from North Africa and other nearby regions while the Middle East and the south of Africa will provide major hydrogen exports to Japan [xviii], as shown in Figure 16. Thus, it will be advantageous for Europe to invest in connectivity with Japanese-led hydrogen supply chains.

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[32] Retrieved from the global Wind Atlas on 15-03-2023: https://globalwindatlas.info/en

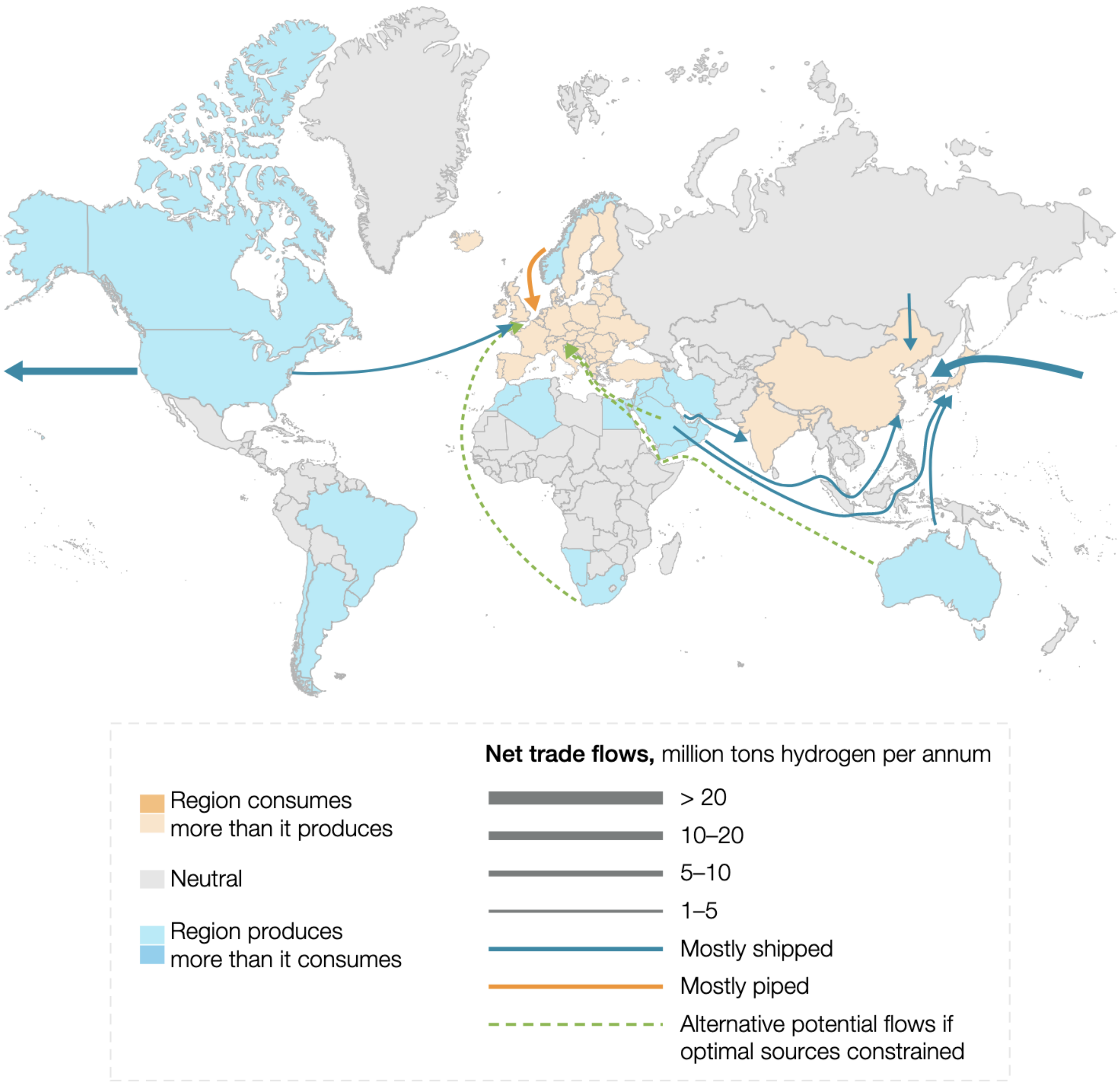

Figure 15, projected hydrogen flows by 2030. Copyright 2022 the Hydrogen Council, expression permission to reuse images in this publication granted.

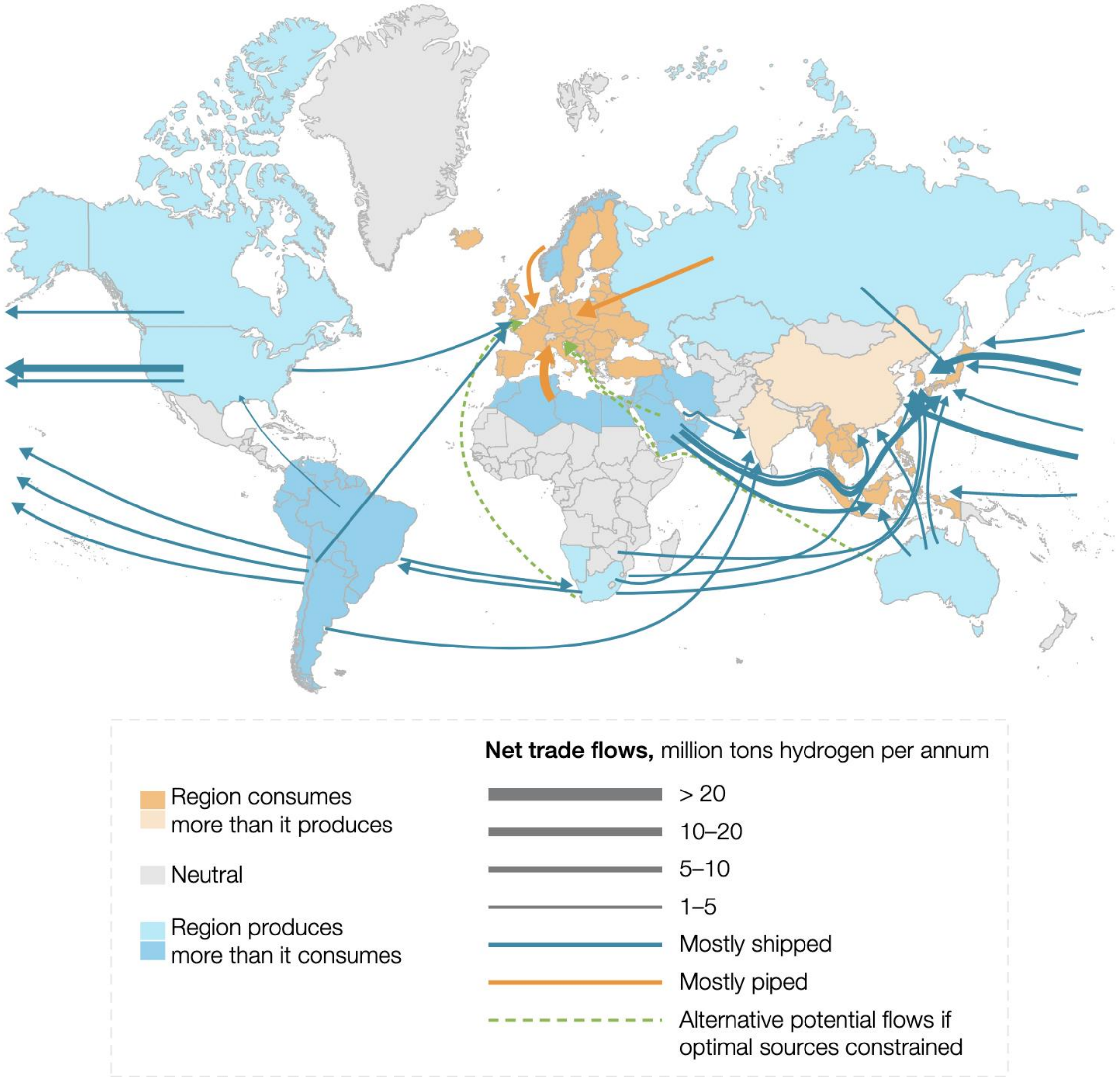

Figure 16, projected hydrogen flows by 2050. Copyright 2022 the Hydrogen Council, expression permission to reuse images in this publication granted.

3.2.2.2. Infrastructure Development

Although Japan might be more focused on ammonia exports from the Middle East and the south of Africa, and the EU on hydrogen itself, EU firms can still benefit from Japan's involvement beyond the specific shipping infrastructure. Furthermore, Japanese firms may have valuable hydrogen shipping experience from AZEC states that they can help employ in Africa or the Middle East.

It might be prudent for EU member states to invest in reserve ammonia import capacity if sudden changes in the market force the EU to find new suppliers for their clean energy needs. This could pre-empt a situation such as what was seen when Russia invaded Ukraine, and the EU had to hastily build new LNG terminals to secure new supply routes.

3.2.2.3. Other Opportunities

Other opportunities for industrial cooperation in the region will be very similar as for Southeast Asia and Australia. These suggestions can be found in sections 3.2.1.3, 3.2.1.4, and 3.2.1.5 above.

3.3. Academic Cooperation

Most experts agree that one of the main areas of cooperation between the EU and Japan will be in the area of R&D. Industrial collaboration might at times be challenging, as both the EU and Japan see a strong internal hydrogen sector as strategic objectives for their energy security and economic resilience. However, both sides have a lot to gain from improvements in hydrogen production efficiency, lowering the need for (critical) raw materials, and establishing a resilient global supply chain for hydrogen.

By collaborating in research, education, and innovation, academic institutions from both regions can contribute to the development of new technologies and strategies that facilitate the transition to a hydrogen-based energy system. Some potential areas of academic cooperation include:

1. Joint research projects: Universities and research institutions from the EU and Japan can collaborate on joint research projects focusing on hydrogen production, storage, distribution, and utilization technologies. These collaborations can help drive innovation, improve existing technologies, and develop new solutions for a hydrogen-based energy system. It is expected that major advances in the efficiency and material use of electrolysers & fuel cells are to originate from universities.

2. Exchange programs: Establishing student and researcher exchange programs between EU and Japanese academic institutions can facilitate the sharing of knowledge, expertise, and best practices. These programs can expose participants to new perspectives, techniques, and approaches, fostering innovation and global collaboration in the field of hydrogen energy.

3. Joint academic conferences and workshops: Organising joint academic conferences, symposiums, and workshops on hydrogen energy can create a platform for researchers, academics, and industry professionals from the EU and Japan to share their findings, discuss new developments, and identify potential areas of collaboration.

4. Collaborative degree programs: The EU and Japan can develop joint degree programs, such as dual or joint master's and Ph.D. programs, focusing on hydrogen energy and related fields. These programs can provide students with a comprehensive understanding of the technical, economic, and policy aspects of the hydrogen economy, preparing them to contribute to the development of hydrogen-based energy solutions.

5. Sharing of research infrastructure: Academic institutions from the EU and Japan can collaborate by sharing research infrastructure and facilities, such as state-of-the-art laboratories, testing centres, and pilot plants. This can help optimize the use of resources, expand the scope of research, and accelerate the development of new technologies and applications.

6. Collaboration on policy and regulation: Academic institutions can collaborate on research related to policy and regulation for hydrogen energy. By studying best practices and successful policy approaches, they can help inform decision-makers and contribute to the development of supportive policy frameworks that enable the growth of the hydrogen economy in both regions.

7. Education and training programs: Developing education and training programs focused on hydrogen energy can help build a skilled workforce capable of supporting the transition to a hydrogen economy. The EU and Japan can collaborate on the development of specialized curricula, training materials, and certification programs for professionals working in the hydrogen sector.

8. Joint book writing: Researchers from the EU and Japan can write academic books collaboratively. These can be aimed at other researchers, as well as at students, industry, and/or policy makers. Collaborative book projects are an excellent way to create a more inclusive knowledgebase. Japanese academics especially have a large share of publications available only in the Japanese language, and international book publications can bring this knowledge to a broader audience.

9. Public-private partnerships: Encouraging public-private partnerships between academic institutions, government agencies, and/or industry stakeholders can help align research and development efforts with market needs, foster innovation, and accelerate the deployment of hydrogen technologies. Universities can also play a key role in establishing international research consortiums with non-academic partners in both the EU & Japan.

One major step forward in the area of academic cooperation would be if Japan were to join Horizon Europe as an associate country. Talks towards this purpose are already underway [33]. Although even without an associated country status, there are many opportunities for academic-academic and academic-industry cooperation between the EU and Japan, both within the Horizon Europe framework and outside of it. Experts interviewed for this report, from both Japan and the EU, have indicated that it can be difficult to identify such opportunities.

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[33] Retrieved on 15-03-2023: https://research-and-innovation.ec.europa.eu/news/all-research-and-innovation-news/eu-and-japan-open-horizon-europe-association-talks-2022-05-12_en

4. Conclusion

This report investigated the potential for cooperation between the European Union (EU) and Japan in developing resilient green/low-carbon hydrogen supply chains that use electrolysers for hydrogen production. It analyses government reports, academic journal articles, research institute publications, and the latest policy developments, alongside interviews with policy makers, political advisors, academic researchers, and industry professionals. The report highlights major areas of potential cooperation between Japan and the EU and explores important third parties for trilateral cooperation, such as the ASEAN, Africa, the Middle East, and Australia.

As the world moves towards decarbonisation, hydrogen is seen as a critical fuel for hard-to-electrify industries and the transport sector. The EU and Japan, as major importers of hydrogen by 2050, have a common interest in creating diversified global supply chains to ensure energy security. The International Energy Agency (IEA) predicts that Australia, the Middle East, North Africa, and Latin America will become major hydrogen exporters, while China and the US will focus on domestic consumption.

The EU and Japan are expected to collaborate in hydrogen consumption industries such as shipbuilding and steelmaking with a more relaxed approach than with strategic hydrogen production technology. Japan, a market leader in boat engines, can leverage its experience in hydrogen-fuelled combustion engines for the marine sector. In steelmaking, Japanese companies may prioritise hydrogenation in their European subsidiaries due to favourable sustainable finance and carbon pricing mechanisms.

Research into hydrogen fuel has led to many patents, some of which have expired or will soon. This offers opportunities for SMEs and start-ups, as seen in the additive manufacturing industry. Both the EU and Japan have filed numerous hydrogen-related patents, and the expiration of these patents can serve as an impetus for new hydrogen sector start-ups.

On-shoring material processing capabilities is crucial for Japan to enhance supply chain resilience, strengthen national security, promote economic growth, and foster innovation. Japan is likely to welcome European companies that can contribute expertise and assist in developing its material processing capabilities. Europe's growing sustainable finance market may also play a role in this regard.

Recycling of large-scale industrial electrolyzers is still in its early stages, but there is an increasing need for efficient recycling facilities and methods as electrolyzers' use grows and lifetimes shorten. Improving the recycling rate of platinum group metals (PGMs) recovered from other industries, such as car exhaust catalytic converters, can benefit both the EU and Japan by reducing competition for primary materials.

Renewable energy is vital for green hydrogen production, and European firms can play a significant role in increasing Japan's wind energy capacity, especially in floating offshore wind power. Currently, wind power accounts for less than 1% of Japan's power supply. However, as green hydrogen production grows domestically, the demand for domestic green power will also increase.

The ASEAN region and Australia offer opportunities for the EU and Japan to cooperate on hydrogen production, transportation, and utilisation. Japan is expected to push connectivity standards in the AZEC region to ensure its energy security and scale up its hydrogen industry.

Compatibility between the EU and Japan standards would be mutually beneficial, as they both benefit from diverse and resilient global supply chains. European firms could participate in infrastructure development in the AZEC region, particularly in areas where the EU has technological superiority. Opportunities also exist in raw material mining and processing markets, such as nickel reserves, which are crucial for alkaline electrolysers. As the EU develops a larger internal demand for hydrogen, European firms may acquire economies of scale benefits earlier than Japanese firms, and can increasingly capitalise on this advantage over time. Japanese firms seeking to expand their hydrogen activities in Southeast Asia and/or Australia might turn towards European financial markets for green hydrogen-related investments.

Similar to the ASEAN and Australia regions, Africa and the Middle East offer opportunities for trilateral cooperation. However, these regions will mostly focus on hydrogen exports rather than imports and domestic use. Arab Gulf states have a strong potential for grey and/or blue hydrogen exports due to their fossil fuel reserves, while Saudi Arabia and Oman have potential for green hydrogen as well. The Middle East is expected to export more hydrogen and ammonia to Japan by 2030, as compared to the EU, with little hydrogen exported from Africa at that point. Though by 2050 it is expected that a lot of hydrogen will be exported from north Africa to the EU, and from the south of Africa to Japan.

North Africa's proximity to Europe allows for the possibility of an international network of hydrogen pipelines, while the Middle East and Sub-Saharan Africa is more likely to export hydrogen to Europe by ship. Also in these regions, good connectivity for shipping hydrogen creates more diverse global supply chains and increases resilience for both Japan and the EU.

The section on multilateral cooperation concludes with recommendations on how governments can better facilitate cooperation between actors in Japan and the EU. These include investing in reserve ammonia import capacity to pre-empt sudden changes in the market and fostering collaboration on hydrogen production, transportation, and utilisation technologies.

Cooperation between the EU and Japan in the hydrogen sector is likely to focus on R&D, as both regions aim to strengthen their energy security and economic resilience. Collaboration in research, education, and innovation can help develop new technologies and strategies for a hydrogen-based energy system. Potential areas of academic cooperation include joint research projects, exchange programs, joint conferences and workshops, collaborative degree programs, sharing research infrastructure, policy and regulation research, education and training programs, joint book writing, and public-private partnerships. A significant step forward would be Japan joining Horizon Europe as an associate country, but even without this status, numerous opportunities exist for cooperation within and outside the Horizon Europe framework.

4.1. Recommendations for the EU-Japan Centre

While the EU-Japan Centre for Industrial Cooperation already has many useful facilities in place, targeting both businesses and innovations & R&D, it might benefit from expanding its science and technology cooperation department. Currently, the centre serves primarily as a national contact point for Horizon Europe in Japan. However, this role could be broadened to include other forms of inter-academic and public-private partnerships in R&D.

Joint R&D is seen as one of the most critical aspects of EU-Japan cooperation, as both regions will heavily rely on a diverse and affordable supply of foreign-sourced hydrogen. Furthermore, other industries will also benefit from increased collaboration in R&D between the EU and

Japan. Positive developments in the talks between Japan and the EU regarding Japan's potential association with Horizon Europe may soon enhance academic cooperation between the regions. However, even in the current situation, there appears to be a strong demand for a service that helps match industry and academics between the EU and Japan, both within the Horizon Europe framework as it stands and outside of the framework.

Referenced Publications

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[i] World Energy Outlook 2022, 2022, by the International Energy Agency.
Retrieved from IEA on 15-03-2023: https://iea.blob.core.windows.net/assets/830fe099-5530-48f2-a7c1-11f35d510983/WorldEnergyOutlook2022.pdf

[ii] Global Hydrogen Review 2022, 2022, by the International Energy Agency
Retrieved from IEA on 15-03-2023: https://iea.blob.core.windows.net/assets/c5bc75b1-9e4d-460d-9056-6e8e626a11c4/GlobalHydrogenReview2022.pdf

[iii] The Future of Hydrogen: Seizing today's opportunities, 2019, by the International Energy Agency
Retrieved from IEA on 15-03-2023: https://iea.blob.core.windows.net/assets/9e3a3493-b9a6-4b7d-b499-7ca48e357561/The_Future_of_Hydrogen.pdf

[iv] Soaring fertilizer prices add to inflationary pressures and food security concerns, 2021, by John Baffes & Wee Chian Koh, in World Bank Blogs
Retrieved from World Bank on 15-03-2023: https://blogs.worldbank.org/opendata/soaring-fertilizer-prices-add-inflationary-pressures-and-food-security-concerns

[v] Evaluation of the Exact Production Quantity of Nitrogen Fertilizer in Real-Time from any Particular Associated Gas Flare Volume in Nigeria, 2017, By Azunna Ekejiuba, for International Journal of Applied Sciences and Technology Vol. 7 No. 3
Retrieved from ResearchGate on 15-03-2023:
https://www.researchgate.net/publication/350790016_Evaluation_of_the_Exact_Production_Quantity_of_Nitrogen_Fertilizer_in_Real-Time_from_any_Particular_Associated_Gas_Flare_Volume_in_Nigeria/figures?lo=1

[vi] Ammonia in agriculture: The engine of plant growth, by Thyssenkrupp
Retrieved from Thyssenkrupp on 15-03-2023: https://www.thyssenkrupp.com/en/stories/sustainability-and-climate-protection/ammonia-in-agriculture:-the-engine-of-plant-growth

[vii] Ammonia Technology Roadmap: Towards more sustainable nitrogen fertiliser production, 2021, by the International Energy Agency, for OECD Publishing
Retrieved from IEA on 15-03-2023: https://iea.blob.core.windows.net/assets/6ee41bb9-8e81-4b64-8701-2acc064ff6e4/AmmoniaTechnologyRoadmap.pdf

[viii] Retrieved from World Bank's World Integrated Trade Solution on 15-03-2023:
https://wits.worldbank.org/trade/comtrade/en/country/All/year/2019/tradeflow/Exports/partner/WLD/product/281410

[ix] A review of advanced methods for ultra-deep desulfurization under mild conditions and the absence of hydrogen, 2023, by Somayeh Gooneh-Farahani and Mansoor Anbia, Journal of Environmental Chemical Engineering Vol. 11 No. 1
Retrieved from Elsevier on 15-03-2023: https://doi.org/10.1016/j.jece.2022.108997

[x] Fuel Cell History, Part 2, by George Wand
Retrieved from The Internet Archive on 15-03-2023:
https://web.archive.org/web/20150402160546/http://www.fuelcelleducation.org/wp-content/themes/sandbox/pdf/Fuel%20Cell%20History%20article.pdf

[xi] Study on impact of deployment of battery electric vehicles (BEV) and fuel cells electric vehicles (FCEV) infrastructure, 2022, by the Clean Hydrogen Joint Undertaking, for the Clean Hydrogen Partnership
Retrieved from the Clean Hydrogen Partnership on 15-03-2023: https://www.clean-hydrogen.europa.eu/media/publications/study-impact-deployment-battery-electric-vehicles-bev-and-fuel-cells-electric-vehicles-fcev_en

[xii] Hydrogen's Decade, 2022, by Thijs van de Graaf, for the International Monetary Fund
Retrieved from the IMF on 15-03-2023: https://www.imf.org/en/Publications/fandd/issues/2022/12/hydrogen-decade-van-de-graaf

[xiii] Clean Hydrogen: A long-awaited solution for hard-to-abate sectors, 2022, by Kellie Nault, for Harvard John A. Paulson School of Engineering and Applied Sciences
Retrieved from Harvard on 15-03-2023: https://seas.harvard.edu/news/2022/10/clean-hydrogen-long-awaited-solution-hard-abate-sectors

[xiv] The potential of hydrogen for decarbonising steel production, 2020, by Christian Kurrer, for the European Parliamentary Research Service
Retrieved from the European Parliamentary Research Service on 15-03-2023:
https://www.europarl.europa.eu/RegData/etudes/BRIE/2020/641552/EPRS_BRI(2020)641552_EN.pdf

[xv] The Path to Green Steel: Pursuing Zero-Carbon Steelmaking in Japan, 2023, by Yuko Nishida, Takanobu Aikawa, Yuri Okubo, Akiko Hirose, and Teruyuki Ohno, for the Renewable Energy Institute
Retrieved from the Renewable Energy Institute on 20-02-2023: https://www.renewable-ei.org/pdfdownload/activities/REI_greensteelEN2023.pdf

---

[xvi] Hydrogen Explained: Use of Hydrogen, 2022, by the U.S. Energy Information Administration
Retrieved from the US Energy Information Administration on 15-03-2023:
https://www.eia.gov/energyexplained/hydrogen/use-of-hydrogen.php

[xvii] Hydrogen Economy Outlook, 2020, by BloomberNEF
Retrieved from BloombergNEF on 15-03-2023: https://data.bloomberglp.com/professional/sites/24/BNEF-Hydrogen-Economy-Outlook-Key-Messages-30-Mar-2020.pdf

[xviii] Global Hydrogen Flows: Hydrogen trade as a key enabler for efficient decarbonization, 2022, by the Hydrogen Council and McKinsey & Company
Retrieved from the Hydrogen Council on 15-03-2023: https://hydrogencouncil.com/wp-content/uploads/2022/10/Global-Hydrogen-Flows.pdf

[xix] Sufficiency, sustainability, and circularity of critical materials for clean hydrogen, 2022, by Susana Moreira and Tim Laing, for International Bank for Reconstruction and Development/ The World Bank and the Hydrogen Council
Retrieved from the Hydrogen Council on 15-03-2023: https://hydrogencouncil.com/wp-content/uploads/2022/12/WB-Hydrogen-Report-2022.pdf

[xx] Critical Raw Materials for Strategic Technologies and Sectors in the EU - A Foresight Study, 2022, by Bobba, S., Carrara, S., Huisman, J., Mathieux, F., and Pavel, C. for the European Union's Joint Research CentreRetrieved from the European Commission on 15-03-2023:
https://rmis.jrc.ec.europa.eu/uploads/CRMs_for_Strategic_Technologies_and_Sectors_in_the_EU_2020.pdf

[xxi] Water Electrolyzers and Fuel Cells Supply Chain - Supply Chain Deep Dive Assessment, 2022, by Alex Badgett, Joe Brauch, Kyle Buchheit, Gregory Hackett, Yijin Li, Marc Melaina, Mark Ruth, Debra Sandor, Morgan Summers, and Shubhankar Upasani, for the U.S. Department of Energy
Retrieved from the US Energy Department on 15-03-2023: https://www.energy.gov/sites/default/files/2022-02/Fuel%20Cells%20%26%20Electrolyzers%20Supply%20Chain%20Report%20-%20Final.pdf

[xxii] China's Nascent Green Hydrogen Sector: How policy, research and business are forging a new industry, 2022, By Alexander Brown and Nis Grünberg, for Merics China Monitor
Retrieved from Merics on 15-03-2023: https://merics.org/sites/default/files/2022-06/MERICS_China_Monitor_No_77_Green-Hydrogen_EN_final.pdf

[xxiii] Electrolysers, 2022, by the International Energy Agency
Retrieved from the IEA on 15-03-2023: https://www.iea.org/reports/electrolysers

[xxiv] Op Weg Naar een Groene Toekomst – Deel 1: Hoe grondstoffen Onze Ambities Voor Groene Waterstof en de Energietransitie als Geheel kan Belemmeren, 2021, by Sara Wieclawska and Anastasia Gavrilova, for TNO
Retrieved from TNO on 15-03-2023: https://publications.tno.nl/publication/34637999/atSPZS/wieclawska-2021-op.pdf

[xxv] Op Weg Naar een Groene Toekomst – Deel 2: Hoe we Grondstoffenschaarste Kunnen Voorkomen en Onze Ambities Voor Groene Waterstof Kunnen Verwezenlijken, 2021, by Anastasia Gavrilova and Sara Wieclawska, for TNO
Retrieved from TNO on 15-03-2023: https://publications.tno.nl/publication/34638160/8OFZQL/gavrilova-2021-op.pdf

[xxvi] Analyzing Platinum and Palladium Consumption and Demand Forecast in Japan, 2017, by Yuna Seo and Shinichirou Morimoto, for Resources vol. 6 No. 4
Retrieved from MDPI on 15-03-2023: https://www.mdpi.com/2079-9276/6/4/61

[xxvii] End-of-life recycling rates of platinum group metals in the automotive industry: Insight into regional disparities, 2020, by Dengye Xun, Han Hao, Xin Sun, Zongwei Liu, and Fuquan Zhao, for Journal of Cleaner Production Vol. 266
Retrieved from Elsevier on 15-03-2023: https://doi.org/10.1016/j.jclepro.2020.121942

[xxviii] Mineral commodity summaries 2021, 2021, by U.S. Geological Survey, 200 p.
Retrieved from USGS on 15-03-2023: https://doi.org/10.3133/mcs2021

[xxix] World Investment Report 2022 – International Tax Reforms and sustainable Investment, 2022, by the United Nations Conference on Trade and Development (UNCTAD)
Retrieved from UNCTAD on 15-03-2023: https://unctad.org/system/files/official-document/wir2022_en.pdf#page=184

Annex A

Japan has been actively engaging with various nations to strengthen its energy security and promote the use of hydrogen as a clean energy source. This report highlights Japan's efforts in forging international partnerships and fostering collaboration in the hydrogen sector through various initiatives, agreements, and forums that happened during the ongoing research period that produced this report.

Collaborations and Agreements in October 2022 – March 2023 period:

1. Signing of the comprehensive Japan-EU Memorandum of Cooperation on hydrogen.
2. Establishment of the Asian Zero Emissions Community (AZEC) with Australia and the majority of ASEAN member states.
3. Japan and Singapore signed a Memorandum of Cooperation (MOC) to develop upstream hydrogen and ammonia production, lowering dependence on LNG supply.
4. Japan and Australia concluded a partnership on critical raw materials, creating a critical mineral supply chain between the two countries.
5. The Ministry of Economy, Trade, and Industry (METI) issued a Joint Media Release for Cooperation on Energy Transition towards Carbon Neutrality with Brunei Darussalam, including hydrogen energy, combine-cycle gas turbine, and carbon capture and storage matters.
6. METI held an online conference with Saudi Arabia's minister of energy, emphasizing the importance of transitioning to cleaner energy systems, particularly renewable and low carbon fuels like hydrogen and ammonia.
7. The Japan Oil, Gas and Metals National Corporation (JOGMEC) and Saudi Aramco signed an MOC to collaborate on the production and storage of hydrogen and fuel ammonia, project support, technology development, and human resource development.
8. JERA Asia and IHI signed a memorandum of understanding to jointly develop the use of ammonia in Malaysia, intending to use ammonia as a fuel mixed with other fuels using co-firing technology in electricity production.
9. Japan and Indonesia announced the development of the Asia Zero Emission Community (AZEC), a cooperation framework to support the energy transition process in the region.
10. JOGMEC and PetroVietnam signed an expanded Memorandum of Understanding (MoU) for joint business opportunities in upstream oil and gas development, as well as cooperation in hydrogen, ammonia, and Carbon Capture & Storage projects.
11. METI co-hosted the 16th Japan-China Energy Conservation and Environment Forum, with breakout sessions on various topics, including hydrogen.
12. JOGMEC and the Government of Western Australia signed an MOU to strengthen cooperation in energy resources, including oil, gas, hydrogen, and ammonia, as well as Carbon Capture Storage (CCS) and Carbon Capture Utilization and Storage (CCUS).
13. Meetings with the United States, discussing energy security, clean energy cooperation, and the importance of clean energy transitions, including hydrogen and ammonia production.
14. Cooperation with the United Arab Emirates, particularly during the Abu Dhabi Sustainable Week 2023, focusing on renewable energy and green hydrogen production.
15. Strengthening ties with Canada in the field of energy, including cooperation on hydrogen and ammonia and clean energy initiatives such as renewable energy.
16. The Fifth Japan-Thailand Energy Policy Dialogue, which saw both countries cooperate on concrete collaborative projects and the realization of the AZEC initiative.

17. JERA's MOUs with Yara International and CF Industries for joint project development and sales & purchase of clean ammonia.
18. Sumitomo Corporation's MOU with Chile's Colbún for green hydrogen and ammonia production and export businesses.
19. JERA's MOU with the Philippines' Aboitiz Power Corporation for a joint study on ammonia co-firing in the Philippines.
20. JERA's MOU with Abu Dhabi’s TAQA to establish joint projects in the area of decarbonization.

International Conferences and Forums

1. METI organized the Tokyo GX Week, an intensive international conference on realizing a global green transformation. Key meetings included the 5th APEC Hydrogen Energy Ministerial Meeting and the 2nd International Conference on Fuel Ammonia.
2. The 24th Japan-Germany Joint Committee Meeting on Science and Technology Cooperation, which discussed cooperation in research fields such as hydrogen technology.
3. The 16th Japan-China Energy Conservation and Environment Forum, which featured a subcommittee on hydrogen.

Japan's foreign policy on hydrogen and decarbonization efforts in 2023 has been characterized by international cooperation, partnerships, and strategic engagements. Through initiatives such as AZEC and various MOUs, Japan is positioning itself as a leader in clean energy and hydrogen technology. This focus on hydrogen and decarbonization aligns with Japan’s goal of being a leader in the global hydrogen economy.

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