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Towards reducing hydrogen supply chain costs

Action plan for collaboration between the Netherlands & Japan

Partner for Progress

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Colophon

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15/170301

Summary

One of the biggest global challenges we face today is how to adapt to- and mitigate climate change. And with its unique proportions, no country can face it alone. To successfully limit the effects of the climate crisis, the global community needs to collaborate. The global energy transition plays a huge role in successfully limiting (the effects of) climate change. It is a cross-sectoral and cross-border system issue in which international efforts should be closely connected. Recent geopolitical developments have only emphasised the urgency of transitioning to renewable energies through international collaboration.

Clean hydrogen has rightfully earned a significant reputation in being a key component in the global energy transition. When produced with green energy, hydrogen does not emit any CO2 emissions. With the potential to hold a significant share in the clean energy mix, green hydrogen is an optimal energy carrier for realising the UNs SDGs. Clean hydrogen can help reduce fossil fuel dependence and decarbonise sectors where other alternatives might be infeasible or more expensive. Worldwide there is an increase in announced and planned national hydrogen strategies which are being adopted by both public and business entities.

"International collaboration is required to support the introduction of technology from abroad to the local context, for scaling investments and accelerate the development of technologies and supply chains. Going international is a must! Diversity and inclusivity too.
Sustainable energy problems and solutions are from and for all of us."

In September 2019, a Memorandum of Cooperation (MoC) on Hydrogen was signed between the Netherlands Ministry of Economic Affairs and Climate and the Japan Ministry of Economy, Trade and Industry. The aim was to enhance cooperation between the two countries in the hydrogen sector. Both countries have ambitious plans to introduce clean hydrogen in their economy and reduce dependence on fossil-based energy resources.

Through innovative cooperation, both countries can strengthen each other in the developments surrounding both the supply of hydrogen and large-scale and broad applications of hydrogen. With a solid partnership for hydrogen development, together we can accelerate our hydrogen economies by engaging in knowledge exchange through innovative collaboration.

As part of a Partners for International Business programme within the Netherlands Enterprise Agency dedicated to the acceleration of hydrogen in Japan, Kiwa N.V., a knowledge institute and international quality authority, was commissioned by the Netherlands Enterprise Agency to identify possible collaboration topics and create an action plan between the Netherlands and Japan to put this into practice. This action plan has a special focus towards reducing hydrogen supply chain costs.

The proposed action plan focuses on (1) the exchange of electrolyser technology, (2) development of harmonised standards and certification schemes at an international level, (3) transparent and better accessible subsidies and lastly (4) a platform for connecting the different players in the hydrogen industry. Such strategic cooperation can help the large scale deployment of essential technologies in individual countries as well as connect organisations from both countries for trade opportunities. This is a step towards achieving economies of scale necessary for cost reduction in the hydrogen supply chain.

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Contents

Acknowledgement

This report is part of research conducted by Kiwa Technology, based on an assignment received from the Ministry of Economic Affairs & Climate (EZK) in the Netherlands. Firstly we would like to thank the EZK for providing funding and opportunity to conduct this research. Furthermore special thanks to Mr. Rob Stroeks and Mr. Takeshi Murakami from the Dutch embassy in Tokyo for providing inputs and sharing contacts for Japanese organisations during the project when needed.

This research was initially planned to be conducted together with a Japanese counterpart to Kiwa. Several organisations were contacted in the beginning phase to discuss this project and the possibility. Although due to time constraints this approach could not be followed, we are still glad that the contacted organisations dedicated their valuable time to discuss this opportunity with them. For this we'd like to extend our gratitude towards the members and professors from Tokyo Institute of Technology, The National Institute of Advanced Industrial Science and Technology (AIST), HySUT and Japan Gas Association.

Heartfelt thanks to all the participating organisations that continuously provided their support by filling in questionnaires, participating in offline discussions as well as the online workshop organised by Kiwa. This study would not have been possible without your participation. These participating organisations are listed in chapter 3.2 of this report. Last but not the least, thanks to members from Partners in Business (PiB) in the Netherlands for supporting and providing an opportunity to present the results and receive feedback from organisations from the hydrogen industry.

Language barriers and distance can sometimes make communication very difficult. We are very glad to receive support from Hastex International K.K. for preparing translations of emails and questionnaires from English to Japanese as well as helping us understand cultural differences when approaching Japanese organisations.

1 Introduction

Clean hydrogen is foreseen as a major player in helping reduce fossil fuel dependence and decarbonising sectors where other alternatives might be infeasible or more expensive. Worldwide there is an increase in announced and planned national hydrogen strategies which are being adopted by both public and business entities. Many national hydrogen strategies include import-export plans, indicating that cross-border hydrogen will grow considerably. However, high costs across the value chain remain as one of the major challenges during the roll-out of hydrogen economy.

There are several mechanisms that help with cost reduction. Scaling up technologies and processes, coherent procurement policies, creating a transparent market by connecting and balancing the demand and supply, innovation in technologies to reduce the costs of material and components, financial instruments to mitigate risks and collaboration are a few examples. International collaboration is desired as it helps with scaling investment, complementing the strengths and weaknesses, as well as sharing experiences, knowledge and risks.

This research conducted by Kiwa Technology, based on an assignment received from the Ministry of Economic Affairs & Climate (EZK) in the Netherlands, as part of the Partners for International Business (PIB) between the Netherlands and Japan, focuses on identifying opportunities where the organisations from the Netherlands and Japan could collaborate with each other in the hydrogen sector.

Hydrogen is a versatile energy carrier with application in different sectors in various forms. Furthermore hydrogen can be stored, transported and produced in many different ways. During this research, four focus segments were identified based on review of ongoing projects in both countries as well as discussions with expert organisations from the Netherlands and Japan. A deeper understanding in the market needs, prominent technologies, common interests and market hindrances was obtained for the identified four segments through questionnaires. These questionnaires were answered by organisations active in the hydrogen industry from both countries. Based on the responses from the questionnaires as well as further discussions with some organisations, topics were identified where both countries could potentially collaborate focusing on innovative collaboration, human resources and localising technologies. This report elaborates the questionnaire findings and the identified collaboration topics. Furthermore recommendations are made on the action plan to boost further possible cooperation.

2 Overview of current state of affairs

2.1 Hydogen supply chain

A hydrogen supply chain is very vast due to its versatility and can be represented in three major sectors as shown in figure 1 below i.e. production, transport & storage, and end use. Developments are required in all three sectors for a successful inclusion of hydrogen. This development should take place not only in terms of technologies and infrastructures but also other indispensable areas, a few examples of which are listed in the figure 1 below.

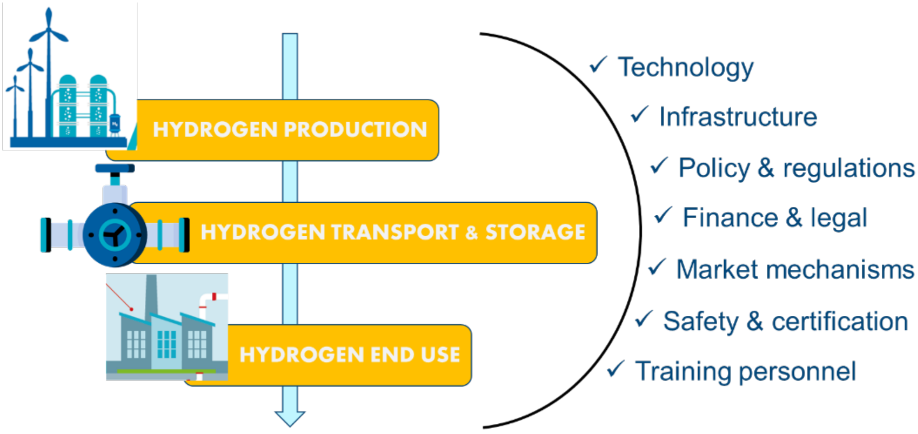


Figure 1: Hydrogen supply chain - a broad overview

2.2 Examples of ongoing H_2 projects in the Netherlands and Japan

Innumerous different projects are already ongoing or being planned in both the Netherlands and Japan with focus on one or more supply chain sectors as well as development areas. Some projects are being implemented on a national or regional level whereas other projects involve international collaboration. Table 1 below lists a few large-scale hydrogen projects both in the Netherlands and Japan.

Table 1: List of hydrogen projects in the Netherlands and Japan

The Netherlands		
Name	**Description**	**Website link**
The Hydrogen Valley 'HEAVENN'	This project intends to develop a fully functioning green hydrogen chain in the Northern Netherlands. The main goal is to make use of green hydrogen across the entire value chain, while developing replicable business models for wide-scale commercial deployment of H_2 across the entire regional energy system.	Heavenn - H2 Energy Applications in Valley Environments for Nothern Netherlands
HyDelta	This Dutch national research programme intends to remove barriers that prevent upscaling of hydrogen. HyDelta aims for safe integration of hydrogen into the	Home - HyDelta

	existing gas transport and distribution infrastructure. Research focuses on: safety of domestic use, piping system components, odorisation, standardisation and education.	
Djewels	Djewels is a project that aims to demonstrate the operational readiness of a 20 MW electrolyser for the production of green fuels (green methanol) in real-life industrial and commercial conditions.	Djewels | Djewels
H2 conversion park	Several large-scale hydrogen factories will produce hydrogen on the Maasvlakte in Rotterdam and share at least electricity and hydrogen infrastructure. From this central location hydrogen will be transported via the open-access Hydrogen Network Rotterdam towards companies in the Port area of Rotterdam. The first electrolysers announced in the conversion park are the 200 MW of Shell (2024) and 250MW of H2-Fifty (BP and HyCC; 2025). The Port of Rotterdam investigates the possibility of importing hydrogen by ship. The aim is to connect overseas hydrogen producers to the North-European consumers and hydrogen market. The hydrogen will be transported and stored attached to a liquid hydrogen carrier, methylcyclohexane (MCH), using Chiyoda's 'SPERA Hydrogen'.	Hydrogen economy in Rotterdam
HyWay27	The realisation of a national high pressure hydrogen transport network, using existing gas infrastructure, to connect users and suppliers to each other and storage facilities. This is a co-operation of Gasunie, Tennet and the Netherlands Ministry of Economic Affairs and Climate that addresses: supply, demand & storage as well as legal & financial and technological & safety issues.	HyWay 27
Hystock hydrogen storage	A power-to-gas-installation of 1MW facilitates energy storage of considerable scale. The aim of this project is to develop subsurface storage sites in salt caverns in the Northern Netherlands. A feasibility study has been completed in 2020 and testing of hydrogen storage in boreholes and subsequent caverns are the next steps.	HyStock hydrogen storage › Gasunie
PosHYdon first hydrogen platform at sea	Green hydrogen will be produced offshore on an operational platform. Subsea cables and transformer stations are highly expensive. The aim of this project is to lower energy transport costs by producing green hydrogen using green electricity from offshore wind parks and sea water and transporting this hydrogen via the existing gas infrastructure to land.	Poshydon | Green Hydrogen Energy
Hydrogen microgrids and Hydrogen City	In Hoogeveen a new district will be developed, solely using green energy and hydrogen. In Lochem, several monumental buildings, that are difficult to isolate and heat, will be converted to be heated with hydrogen instead of natural gas. The Dutch town of 'Stad aan 't Haringvliet' even aspires to switch from natural gas to hydrogen completely. The aim is to produce hydrogen locally and facilitate heating of 600 houses.	Waterstof Hoogeveen - Waterstof Hoogeveen Edit Jan-2024: new link www.alliander.com/nl/energietransitie/pilots-met-waterstof/lochem/ Stad Aardgasvrij - Hydrogen City -

		H2GO (h2goeree-overflakkee.com)
Elektrolyser makersplatform NL	This platform is created jointly by TNO and FME to accelerate production of electrolysers in the Netherlands. This platform connects interested parties with one another as well as end users and government bodies. Furthermore events such as workshops, matchmaking, knowledge exchange etc. are organised.	Elektrolysermakersplatform
Japan		
Name	**Description**	**Website link**
HESC	The world-first Hydrogen Energy Supply Chain (HESC) Project aims to safely produce and transport clean liquid hydrogen from Australia's Latrobe Valley in Victoria to Kobe in Japan. Hydrogen was extracted from Latrobe Valley coal and a mixture of biomass at a newly constructed plant located at AGL's Loy Yang Complex in the Latrobe Valley through gasification and refining.	Hydrogenenergysupplychain Kobe Australia
AHEAD	Japan's Advanced Hydrogen Energy Chain Association for Technology Development, or AHEAD, launched its pilot project to produce hydrogen by steam reforming processed gas from the Brunei LNG liquefaction process. The hydrogen is converted by hydrogenation reaction using toluene into methylcyclohexane (MCH). The MCH is shipped to Tokyo Bay, where the hydrogen is extracted using a new dehydrogenation plant.	AHEAD JP
Keihin coast area	This project develops a hydrogen supply chain that includes production of CO_2-free hydrogen using water electrolysis utilising wind energy, storage and transportation as well as use of hydrogen in fuel cells based forklift.	Lowcarbon H2 demo Keihin coastal area
Tomiya, Miyagi Prefecture	Hydrogen is produced in electrolysers using electricity produced from solar plant. Hydrogen is stored and transported in metal hydride cartridges. The hydrogen here is used to supply electricity and heat through pure hydrogen fuel cells at a store, other facilities and several residential houses, by taking advantage of the existing logistics network of Miyagi Coop.	Demo Tomiya Miyagi Prefecture
RE100 demo facility	Panasonic built a large facility at its Kusatsu site in Shiga Prefecture, which is equipped with an in-house power generation system that combines pure hydrogen fuel cell generators (500 kW) and photovoltaic generators (approx. 570 kW), as well as lithium-ion storage batteries (approx. 1.1 MWh) for storing surplus power.	Panasonic RE100
Yamanashi prefecture	Yamanashi Prefecture's hydrogen and fuel cell project has a cluster of research centers including the University of Yamanashi, covering the full cycle from hydrogen production to use. One of the demo projects is a power to gas project where excess electricity from solar plants is used to produce hydrogen which is then stored in tanks and fed to fuel cells. Hydrogen in future is foreseen to also be transported in trailers or injected in the customer	Yamanashi fuel cell and hydrogen valley

	pipelines for use in pure hydrogen fuel cells and boilers.	
Fukushima Hydrogen Energy Research Field (FH2R)	FH2R uses 20MW of solar power generation facilities along with power from the grid to conduct electrolysis of water in a renewable energy-powered 10MW-class hydrogen production unit. Adjustments to imbalance in the power grid can be made by adjusting the produced hydrogen volume by the hydrogen production unit. Hydrogen produced at FH2R will mainly be transported in tube trailers and bundles, to be supplied to users in Fukushima Prefecture, the Tokyo Metropolitan Area, and other regions.	FH2R
Kitakyushu Hydrogen Town	Hydrogen Town in the Higashida district of Kitakyushu City, the world's first demonstration in 2011 where hydrogen was supplied to homes, museums, etc. using pipelines. The hydrogen was by-product from steelmaking process and was utilised in 14 pure hydrogen fuel cells for multiple applications, installed in apartments, commercial facilities and hydrogen fueling stations; fuel cell-powered small vehicles, such as forklifts and bicycles. The project also tested electricity supply from FCVs to houses.	Kitakyushu H2 town

These are just a few examples out of the large number of hydrogen related projects ongoing in both countries. It is very apparent that several different technologies are applied in different parts of the supply chain. Some examples are coal gasification, steam reforming, water electrolysis for hydrogen production; the use of gas pipelines, metal hydrides, liquid tanks, and compressed gas tanks for hydrogen transport & storage.

2.3 Examples of knowledge consortiums in the Netherlands and Japan

Apart from the abovementioned projects, knowledge consortiums and collaboration groups also play a major role especially in Japan, in the deployment of hydrogen technologies. Such consortiums consist of diverse companies with different expertise and development status. The consortiums provide a platform for knowledge sharing and means to develop & implement specific solutions.
Below are a few examples of such consortiums both in the Netherlands and Japan:

- Japan Energy Transition Initiative (JETI) – Consists of stakeholders from finance, business, policy and civil society with focus towards clean energy transition in Japan.
- Japan Hydrogen Mobility (JHyM) – Consists of private companies such as refueling station developers, automobile manufacturers, financial institutions and other stakeholders working towards deployment of Hydrogen Refueling Stations (HRS).
- CO2-free Hydrogen Energy Supply-chain Technology Research Association (HySTRA) – Consists of a few companies with the aim to jointly demonstrate a hydrogen supply chain from production, transport and storage up to utilisation.
- Japan Hydrogen Association (JH2A) – Consists of hydrogen related stakeholders contributing to strategy development.
- The Association of Hydrogen Supply and Utilisation Technology (HySUT) – Consists of several companies and organisations engaging in activities like

technological development & research, education/training and standardisation in the field of HRS.

- Japan Automobile Research Institute (JARI) – Involved in research & technology development, standardisation, testing & evaluation of fuel cells based automobile.
- Fuel Cell Commercialisation Conference of Japan (FCCJ) -Focuses on research, development, commercialisation and popularisation of the fuel cell related technology proactively by offering opportunities for a number of private companies and organisations.
- Japan Gas Association (JGA) – Consists of city gas utilities promoting the development of gas utilities business, gas pipelines and major gas related projects.
- Hydrogen Energy Systems Society of Japan (HESS) – Consists of universities and industries with the aim to foster the research and development of hydrogen technologies, and organise activities such as symposiums, workshops, tours and exhibitions to assists information exchange and information transfer among government, industry, academia and members.
- Op weg met waterstof (H2Platform) – Partnership of approximately 60 companies and organisations involved in the production, import, transport, storage and deployment of hydrogen with the sole aim of knowledge sharing and networking.
- Netherlands Energy Research Alliance (NERA) – Consists of almost all academic research organisations in the Netherlands with the motives of knowledge sharing, co-ordination and co-operation in energy research.
- Netbeheer Nederland (NBN) – Consists of all energy network operators in the Netherlands working jointly in design, construction and management of the necessary energy infrastructure.
- Nederlands Waterstof & Brandstofcel Associate (NWBA) – Consists of different companies and provides a platform for knowledge sharing and supporting the implementation of hydrogen and fuel cell applications in the Netherlands.

3 Questionnaire findings and topics for collaboration

3.1 Focus segments

Diving further into the generic hydrogen supply chain sectors, studying the ongoing projects and based on interviews with different organisations, the four topics depicted in figure 2 were identified as the most promising focus segments for collaboration opportunities between the Netherlands and Japan.

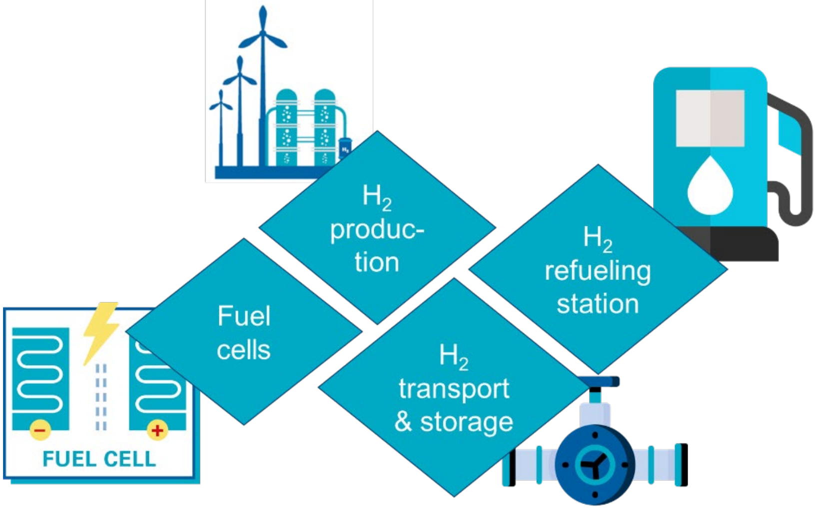


Figure 2: Focus segments for collaboration opportunities

3.2 Participating organisations

Understanding the market needs, obstacles, trade possibilities, implemented technologies and production capabilities is essential to identify the most relevant topics where collaborations could take place. After all, the idea behind collaboration is utilising each other's strengths and helping overcome the weaknesses. Such information was obtained during this research on a first hand basis from a few expert organisations active in the field of hydrogen in the Netherlands and Japan with the help of questionnaires. In total 22 organisations participated out of which 14 organisations are from Japan and 8 from the Netherlands.

Below is a list of all the participating organisations who have immensely contributed to this study by providing their opinions and participating in discussions.

- Asahi Kasei Corporation
- Chiyoda Corporation
- Fujikin Incorporated
- Hitachi Zosen Corporation
- Howden Thomassen B.V.
- HyCC
- Japan Gas Appliances Inspection Association (JIA)

- Japan Hydrogen Association
- Kawasaki Heavy Industries, Ltd.
- Koninklijke Vopak N.V.
- Osaka Gas Co., Ltd.
- Panasonic Corporation
- Port of Amsterdam N.V.
- Port of Den Helder N.V.
- Resato Hydrogen Technology B.V.
- SHV Energy N.V.
- The Institute of Applied Energy
- TNO
- Tokico System Solutions, Ltd.
- Tokyo Institute of Technology
- Toshiba Energy Systems & Solutions Corporation
- WE doubleyouenergy B.V.

3.3 Key results from the questionnaire

A summary of the key take away points derived from the questionnaire responses for the 4 focus segments is presented in the following sections. The findings are divided into 3 categories – (1) Technology, (2) Market & deployment challenges, and (3) Country specific challenges & opportunities.

These categories help to answer the following questions:

1. What technologies have preference in both countries?
2. What are the roadblocks to faster & large-scale implementation of hydrogen technologies?
3. What are the strengths & weaknesses of both countries?

3.3.1 Hydrogen Production

Technology:
There are several different methods for hydrogen production but water electrolysis using renewable energy is at the forefront due to its capability to produce green hydrogen directly. Many large and small scale electrolysers are being implemented in both countries.

- ✓ Based on the questionnaire responses, *proton exchange membrane* electrolysers seem to have the most market potential in both countries. Further, there is also interest in solid oxide and alkaline electrolyser technology.
- ✓ Apart from electrolysis, both countries have keen interest in hydrogen production using *steam methane reforming* and *ammonia cracking.*

Market & deployment challenges:

- ✓ *High manufacturing costs* and availability of renewable electricity are two factors hindering the large scale deployment of electrolysers.
- ✓ There is a lack of clarity in procedures & permitting processes discouraging and delaying project implementation.
- ✓ *Reduction in renewable electricity costs* is desired, especially in Japan, to lower the costs of hydrogen.
- ✓ There is less incentive and desire in the market for green hydrogen due to very high costs. It is suggested that well-established *CO_2 pricing policy* implementation is required to make green hydrogen more desirable and cost

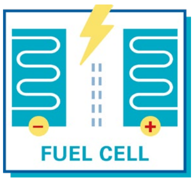
competitive. Further market regulations & incentives need to be in place to make green hydrogen a necessary target.

- ✓ There is a *disconnect between demand and supply*. Platforms need to be in place to connect hydrogen producers with the end users. Lack of offtake agreements is hindering the electrolyser project financing.
- ✓ *Standardisation and certification processes* need to be well defined, preferably in an international setting.

Country specific challenges & opportunities:

- ✓ Very few electrolyser manufacturers exist in the Netherlands whereas Japan has several manufacturers offering commercial systems. This is one of the reasons why the Netherlands is involved in more international projects when it comes to electrolysers as compared to Japan.
- ✓ Both countries have interest in *importing large scale H_2*, especially via ports, since locally produced H_2 will not be sufficient to meet the demand. This creates the opportunity to develop the import infrastructure for liquid H_2 and vectors like ammonia.
- ✓ Both countries are accelerating the implementation of renewable electricity generation plants like solar and wind parks.

3.3.2 Fuel cells



Technology:

- ✓ *Proton exchange membrane* (PEM) fuel cells are considered to have the most market potential in both countries. There is also interest in solid oxide fuel cell technology.
- ✓ Fuel cells are majorly used in passenger vehicles & residential *combined heat & power (CHP)* systems in Japan. In both the Netherlands & Japan, fuel cells are being incorporated in *mobility applications* like buses, trucks, other heavy duty applications as well as stationary power plants & industrial CHP.

Market & deployment challenges:

- ✓ *High manufacturing costs* and *lack of cost effective hydrogen availability* are seen as major roadblocks hindering large scale deployment.
- ✓ Furthermore there is little awareness and confidence in the technology leading to a *lack of customers* and hence low market demand in stationary applications.

Country specific challenges & opportunities:

- ✓ Very few fuel cell stack manufacturers are positioned in the Netherlands. There are however system integrators. Japan is relatively more advanced with commercially offered fuel cell stacks as well as systems.
- ✓ Both countries have *limited involvement in international projects* when it comes to fuel cell applications.
- ✓ De-regulation of market is desired by the Japanese parties to improve competition and create a free market.
- ✓ Industrial deployment and scale-up is necessary for cost reduction. Collaboration between companies can help lower the burden of risks and costs as well as implement large scale sales.
- ✓ Use of *H_2 technology for grid stabilisation* has interest in Japan.

3.3.3 H_2 transport & storage

Technology:

Several different methods for hydrogen transport & storage are being explored in both countries. Depending on the geographical conditions and existing infrastructure, different technologies are given preference. The below figure 3 lists the technologies of interest in both countries for regional and international transport as well as storage of hydrogen.

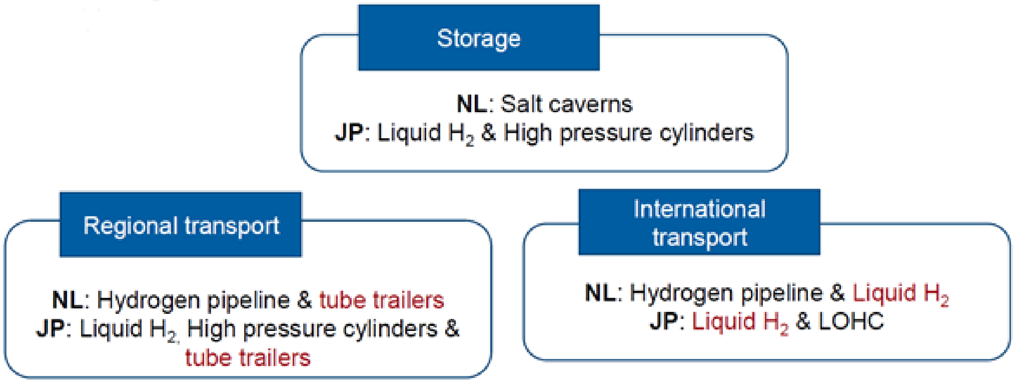


Figure 3: Technologies prominent in both countries for hydrogen transport and storage (the common technologies are highlighted in red)

Market & deployment challenges:

- ✓ There is a *disconnect in the market*. The producers need to be well connected with the end users. Today lack of offtake agreements is hindering the hydrogen transport and storage deployment.
- ✓ *High starting costs,* and *lack of clarity in import duties* are seen as some of the main roadblocks in large scale deployment of projects.
- ✓ Government's role in establishing regulations and funding opportunities can enable faster implementation.
- ✓ Furthermore, *standardisation and certification* processes as well as safety assessment needs to be properly defined.
- ✓ *Lack of trained personnel* is another roadblock hampering the implementation.
- ✓ H_2 market transparency, carbon tax and increased market demand are mechanisms expected to help make the technology profitable without subsidies.

Country specific challenges & opportunities:

- ✓ Dehydrogenation units & ammonia crackers are currently being imported from other countries to the Netherlands.
- ✓ Both countries are working in international collaborations involving hydrogen transport.
- ✓ Both countries have some *similar geographical conditions* like port areas, high population density, narrow lands and hence interest in similar infrastructure. Furthermore, both countries have great industrialisation potential but do not have enough renewable energy potential to produce sufficient H_2 locally to meet the future estimated demand.

3.3.4 H_2 refueling station (HRS)

Technology:

- ✓ Japan sees deployment of HRS at 700 bar hydrogen pressure whereas in the Netherlands both 350 and 700 bar stations are being installed.
- ✓ Research in methods & system design to increase the station availability and *reduce the downtime* can help with reduction of operational costs of HRS.

Market & deployment challenges:

- ✓ *Lack of customers and high starting costs* are seen as the major roadblocks in the large-scale deployment of HRS.
- ✓ HRS industry is highly dependent on the deployment of hydrogen vehicles. *Increase in the hydrogen vehicles* is necessary for scaling up HRS.

Country specific challenges & opportunities:

- ✓ Japan has fuel dispenser manufacturers whereas many system integrators in the Netherlands import fuel dispenser required in the HRS's.
- ✓ Very few (almost none) of the participating organisations both in the Netherlands and Japan are involved in international projects.
- ✓ *Subsidies for HRS* are few in the Netherlands.

It can be deduced from the key conclusions from the four focus segments that every segment has its own set of challenges and opportunities. There are however a few conclusions that are common to all focus segments. These common conclusions are the topics that should be addressed with high priority to quickly scale the hydrogen industry. The common conclusions are summarised below.

- ➢ Well established CO_2 pricing policy is necessary for making green hydrogen cost competitive.
- ➢ High starting and manufacturing costs is one of the roadblocks applicable to all hydrogen technologies, reiterating the need for subsidies and collaboration.
- ➢ Subsidy remains important to launch businesses and implement large scale international projects demonstrating all segments of hydrogen technologies. Both national & international subsidies are necessary for implementation of hydrogen technologies. These subsidies and projects must be well distributed amongst small and medium scale enterprises to create equal competition.
- ➢ International collaboration is desired as it helps with scaling investment, complementing the strengths and weaknesses, as well as sharing experiences, knowledge and risks.
- ➢ Economies of scale, automation and increase in availability of components from various equipment manufacturers can contribute in bringing the costs down.
- ➢ The players in the hydrogen supply chain remain distant and should be better connected.
- ➢ There is a need for international standardisation and harmonised certification processes.
- ➢ Training of personnel is of utmost importance to ensure availability of skilled personnel.

3.4 Possible collaboration topics

Making use of the questionnaire findings and the developments in the hydrogen industry in both countries, a few co-operation topics have been identified. These topics are deduced by identifying the areas:

- Where one country could complement or fill in the gaps for the other country
- Where both countries see the most potential in terms of technologies and similar applications
- Where both countries lack developments

The possible cooperation topics are classified into three main topics – 1) Innovative collaboration, 2) Human resources and 3) Localising technologies. The topic 'innovative collaboration' consists of collaboration focused on knowledge sharing, researching and development of technologies. The topic 'human resources' mentions the need for building knowledgeable workforce as well as the need for platforms where the players from different sectors in the hydrogen chain can be connected with each other. Lastly the topic 'localising technologies' proposes co-operation when implementing solution in each other's country and dealing with policies, standards, procedures and certification schemes.

Innovative collaboration:

- *Developing infrastructure for H_2 import:*
  - Both countries have similar geographical conditions and desire to import hydrogen through existing ports. Several international projects have been ongoing in both countries to demonstrate this technology. Both countries should work together by sharing knowledge and together demonstrating and improving the hydrogen transport technology and import infrastructure.

- *Joint research on the use of hydrogen technology for grid stabilisation:*
  - The use of renewable energy from wind and solar plants has been increasing. Furthermore, the electrolyser installations demand large scale installations of the fluctuating wind and solar power plants. The unpredictable nature of wind and solar power make the electricity grids unstable. Hydrogen production and use can help stabilise the grid by powering on the electrolysers at times of high energy production and fuel cell systems at times of high energy demand. There is potential for joint research on design, optimisation and demonstration of the use of hydrogen technology for grid stabilisation.

- *Electrolyser technology:*
  - Shared research on cost reduction of electrolyser system by means of improved efficiency, cheaper material use, automation in production and implementation of large scale demonstrators.

Human resources:

- *Personnel training:*
  - With increasing interest in hydrogen, the implementation of hydrogen technologies is accelerating. The availability of trained people however is not advancing at the same pace as the implementation. There is an urgent need to secure highly experiences specialists to support the roll-out of the hydrogen infrastructure. In response both countries must launch educational and practical training programs for human taskforce in all different stages, i.e. design, installation, operation, repair and maintenance of systems.

- *Testing & certification:*
  - In consultation with the notified bodies in the Netherlands and Japan, accredited training programs should be established to train qualified professionals who can test, inspect and certify hydrogen products and installations.

Localising technologies:

- *Policy making for CO_2 pricing:*
  - Well defined policies for CO_2 pricing is desired in both countries to make green hydrogen cost competitive. Both countries can work together in supporting the formulation of such policies.

- *Residential combined heat and power (CHP)*:
  - Japan has about 400,000 residential CHP systems installed that have been running for about 10 years now. CHP systems have potential in residential, horticulture and other industries in the Netherlands to replace the existing natural gas based heating systems. There is interest from Dutch companies to import the technology and learn from the experiences of Japan in fuel Cell based CHP.

- *Hydrogen refueling stations (HRS):*
  - Both countries are focusing on different applications when it comes to HRS. HRS is installed for fuel cell vehicles in Japan whereas in the Netherlands in addition HRS at ports for refuelling hydrogen based small ships are also being investigated. In Japan the role of knowledge consortium like HySUT has played a vital role in the wide deployment of HRS. Such a similar consortium can help accelerate the deployment in the Netherlands. Knowledge sharing and collaboration can help with system improvement to increase the operating times and availability of refueling stations.

- *Permitting procedures:*
  - Both countries lack well established permitting procedures for hydrogen system installation. A team of experts with technical and legal background in both countries can work together with the government bodies to establish and elaborate the necessary permitting process and other procedures for hydrogen system installation. Such information can be made readily available as public documents to help companies enter the market in both countries and ease technology deployment.

4 Action plan

Identification of collaboration topics is important, however it cannot be put to use without a proper action plan. The questionnaire findings and identified collaboration topics were discussed with several organisations from the Netherlands and Japan to understand and prioritise some topics that need utmost attention. An action plan is thereby proposed which is in line with the expectations, interest and needs of organisations in the hydrogen sector. Concrete steps have been identified to tackle the most pressing topics.

1) Standardisation, testing & certification:

Two of the most significant barriers to the deployment of hydrogen in both the Netherland and Japan resulted to be lack of standards and certification, and permitting procedures. Furthermore, it is desirable to establish regulations and standards that are harmonised and acceptable at the international level.

Create a working group with relevant experts and notified bodies (certification companies) to compare the current available Dutch and Japanese standards, and type approval protocols for all four focus segments. Further define harmonised certification schemes and testing protocols especially for the identified focus segments like fuel cells, CHP, HRS, electrolysers and other system components. This will also help stimulate the import and export of hydrogen products between the two countries. The working group in co-operation with other relevant bodies (e.g. CEN, CENELC, JISC, etc) should also aim to contribute to the development of hydrogen standards for those segments where standards do not exist yet.

2) Electrolysers:

Both countries have potential and interest in green hydrogen production using electrolysers. The Netherlands lacks companies specialised in electrolyser manufacturing whereas Japan has several companies offering electrolyser systems. To boost the electrolyser knowledge in the Netherlands, FME and TNO have created the ‘electrolyser makers platform’ to help connect parties and share knowledge. Such an initiative at an international setting between the Netherlands and Japan can help sharing of knowledge and learnings on a wider level.

Matchmaking events should be organised to connect electrolyser manufacturers with the buyers to enable introduction of electrolysers from Japan to the Dutch market. This will help connect the appropriate parties in both countries that can work together on joint demonstration projects as well as large-scale installations.

3) Hydrogen network:

It has been consistently apparent during discussions with the participating companies that there is a disconnect between the different players in the hydrogen supply chain. The hydrogen industry is very wide with players involved in hydrogen production, transport, storage and end use. Establishing a link between these players is very important.

It is recommended that an unbiased organisation (like advisory or consulting companies, or a certification body) takes the responsibility to create a joint platform for hydrogen related organisations in the Netherlands and Japan. This platform should provide support in individually introducing and connecting the players, for example the hydrogen producers with end users, hydrogen based vehicle manufacturers with HRS companies, electrolyser manufacturers with buyers. Matchmaking events and workshops should be organised through this platform to establish collaboration opportunities and identify potential international projects. Thematic clusters can be formed within this network to trigger co-operation, and facilitate the exchange of knowledge.

4) Subsidies:

High manufacturing costs remain a roadblock to large scale deployment of hydrogen technologies. Both national and international subsidies remain important to launch businesses and implement large-scale projects. These subsidies and projects however need to be well distributed amongst small and medium scale enterprises to create equal competition.

Informative sessions should be organised to inform companies of the available subsidies and the procedures involved. Several platforms that provide an overview of available as well as spent national and international funds exist and are being actively updated. One such example is the Hydrogen Public Funding Compass Funding guide (europa.eu), a tool developed by the European Commission. Webinars should be held to make such platforms known where the navigation and use of such tools can also be demonstrated.

5 Concluding remarks

A Memorandum of Co-operation (MoC) on Hydrogen was signed between the Ministry of Economy, Trade and Industry of Japan and the Ministry of Economic Affairs and Climate Policy of the Netherlands in September 2019 with the objective to enhance co-operation between the two countries in the hydrogen sector. Both countries have ambitious plans to introduce green hydrogen in their economy and reduce dependence on traditional fossil based energy resources.

Both the Netherlands and Japan are implementing schemes for local production as well as large scale import of green hydrogen. There are several areas in the hydrogen supply chain where both countries can complement each other. The Netherlands has very limited number of equipment manufacturers in the hydrogen sector. This provides an opportunity to introduce Japanese technology to the Dutch market. This is especially true for electrolysers, fuel cells based CHP systems and specific hydrogen system components. There is potential to learn from each other and optimise developments such as HRS, fuel cells in mobility and hydrogen transport and storage technologies.

Both countries are facing similar challenges like lack of harmonised standards, certification schemes, CO_2 pricing policies as well as fair availability and distribution of subsidies. This provides opportunity to jointly develop schemes that can promote easy deployment of products, make green hydrogen cost competitive as well as at the same time also help ease the trade of products between both the countries.

The proposed action plan focuses on exchange of electrolyser technology, development of harmonised standards and certification schemes at an international level, formation of clear permitting procedures, transparent and better accessible subsidies and lastly a platform for connecting the different players in the hydrogen industry. Such strategic co-operation can help the large scale deployment of essential technologies in individual countries as well as connect organisations from both countries for trade opportunities. This is a step towards achieving economies of scale necessary for cost reduction in the hydrogen supply chain.

Appendix 1: Knowledge Institutes in Japan identified during the project that could have acted as potential counterparts to Kiwa for this study

Organisation name	Organisation type	Website link
Japan Science & technology Institute (JST)	Public research organisation	https://www.jst.go.jp/EN/
National Institute of Advanced Industrial Science and Technology (AIST)	Public research organisation	https://www.aist.go.jp/index_en.html
Fukushima Renewable Energy Institute (FREA)	Research Institute	https://www.aist.go.jp/fukushima/en/
National Institute for Materials Science (NIMS)	Public research organisation	https://www.nims.go.jp/eng/
Yokohama National University Institute of Advanced Sciences	University	https://acerc.ynu.ac.jp/en/_hyd/
Tokyo Institute of Technology	University	https://aes.ssr.titech.ac.jp/english
Kyushu University	University	http://h2.kyushu-u.ac.jp/english/index.html
HySUT	Knowledge Institution	http://hysut.or.jp/en/
Japan H2 mobility (JHyM)	Knowledge Institution	https://www.jhym.co.jp/
The Institute of Energy Economics (IEEJ)	Think tank	https://eneken.ieej.or.jp/en/
Japan Hydrogen Association (JH2A)	Knowledge Institution	https://www.japanh2association.jp/
Japan Energy Transition Initiative (JETI)	Think tank	https://jeti.eco/