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Position Paper

ROTTERDAM HYDROGEN HUB

Disclaimer

This position paper was written by SmartPort as input for the SmartPort CEO Dinner on September 23rd, 2019. The paper is the starting point for the discussion and summarizes the current 'state of art' in the hydrogen world, including initiatives in the Rotterdam region that have already commenced to show their common denominators and signal developments already in place. This paper by no means provides an exhaustive overview of all projects. It is meant to take the development of hydrogen in the port of Rotterdam region a step further by focusing on research questions. Gathered scientific knowledge will enable next steps in H2 market and infrastructure development. This position paper is property of SmartPort and for non-commercial use only.

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1. INTRODUCTION

Big challenges regarding the availability of electricity infrastructure and the emissions of CO₂ are rising. The port of Rotterdam committed to reduce its emissions of its industrial cluster and its effect on transport movements from and to the port. The mobility sector and the industrial cluster both emit around 30 Mton of CO₂ per year. In various emission-free future visions hydrogen takes on these challenges. Therefore, the Dutch government recently gave hydrogen a prominent place in the Dutch Climate Agreement for the energy transition of the Dutch economy¹. A hydrogen program will be developed to support ongoing (blue) hydrogen projects from 2019 until 2021. From 2022 until 2025, the program is aimed at realizing cost reduction for electrolysis technologies and thereby accelerate the development of installed electrolysis capacity to 500 MW. The last phase of the planned program should facilitate the upscaling of this capacity to 3 to 4 GW, the development of sufficient hydrogen storage facilities, the expansion of hydrogen infrastructure, and the enlargement of renewable electricity production. For the achievement of this ambitious plan the port of Rotterdam is considered to have a key position.

Moreover, the International Energy Agency² pointed out that industrial ports, such as the port of Rotterdam, are the aspired nerve centers of the future hydrogen economy. Firstly, because refineries and chemical production sites, which are often located industrial clusters of ports, already use hydrogen based on fossil fuels on a large scale. Secondly, because these plants are concentrated at coastal areas, such as the North Sea, where wind electricity generation is feasible. And lastly, because the application of hydrogen in the transport to and from the port area seems to be promising. Trucks, barges, and ships could be equipped with fuel cells running on hydrogen instead of the current fossil fuel engines and a reduction of the mobility emissions, that comprise around 21% of the total Dutch emissions, could be realized.

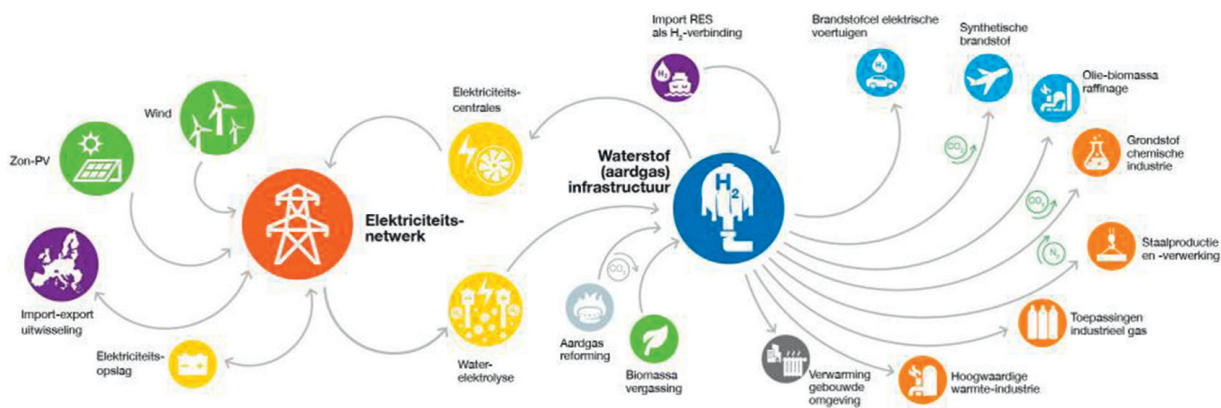
Much research is already done and many reports exist that provide detailed visions of a hydrogen future on a national and international level, among which the 3 step roadmap of the Port of Rotterdam Authority, the outlook of a green hydrogen economy of the Province of South Holland, the assessment of hydrogen by the International Energy Agency, and the feasibility study of a blue hydrogen production plant (H-Vision). This position paper aims at providing stakeholders in the region of the port of Rotterdam an overview of the components of the hydrogen economy. SmartPort, the initiator of this position paper, aims at furthering the energy transition of the port by providing the necessary pre-competitive knowledge to remove barriers for taking action and realizing the innovations of the future.

1 *Klimaatakkoord, (2019).*

2 *IEA, (2019), The Future of Hydrogen*

2. CONSIDERED APPLICATIONS OF H₂

Figure 1. Hydrogen applications



source: TKI Nieuw Gas. [<https://www.topsectorenergie.nl/tki-nieuw-gas/waterstof>]

2.1. Adoption in refining and chemical processes

Although hydrogen is lately presented as a solution for the future, it is already widely used in various industrial processes. This current production of around 300 to 400 kton hydrogen a year is mostly produced through steam methane reforming. Refineries within the industrial cluster of Rotterdam mainly use the hydrogen as a feedstock to upgrade heavy oil fractions and for desulfurization of fuels. Because of the fact that in the future a higher quality of fuels is demanded and the policies on sulphur emissions become stricter, this demand for hydrogen as a feedstock is expected to rise. The chemical industry uses hydrogen for the hydrogenation of unsaturated links: a part of the production process of various products, among which plastics³.

Another application for hydrogen could be to serve as a replacement for fossil fuels for heating processes. At this moment, efforts are made to decarbonize heating processes within the industrial cluster by electrifying them. The electrification of high temperature heating processes is however still infeasible on a large scale. Hydrogen, on the other hand, is a qualified sustainable alternative⁴.

Hydrogen could also be used as a feedstock for the production of synthetic fuels. Through electrochemical processes, CO₂ and hydrogen can be converted into, amongst others, methane or kerosene. When captured CO₂ emission is used as a feedstock for this conversion process, previously emitted emissions can be transformed into new fuels. A closed carbon cycle is thereby established.

The pressure of the competitive international market for oil and chemical products combined with the ambition to reduce emissions in the port could be disastrous for the industrial cluster of the port of Rotterdam. However, a transition to a petrochemical cluster that incorporates new business opportunities based on hydrogen application could secure a position for the industrial cluster in an emission-free world.

³ VNPI and H-Vision (2019) report.

⁴ H-Vision (2019) report, CE Delft (2018), "Feasibility Study into Blue Hydrogen" and "In drie stappen naar een duurzaam industriecluster" (2018), [<https://www.portofrotterdam.com/sites/default/files/downloads/in-drie-stappen-naar-een-duurzaam-industriecluster-rotterdam-moerdijk-in-2050.pdf?token=SnEuvvqX>].

2.2. An alternative fuel for mobility

Hydrogen is one of multiple fuel options to decarbonise transport. Fuel cells are able to convert pure hydrogen into electrical power for electric engines. Hydrogen fuel produced from electricity (e-H₂) is projected to reach a price that is competitive to current fossil fuel alternatives. For e-H₂, 82% of the cost price is dictated by the price of renewable electricity⁵. Next to the fuel cell, hydrogen could be used to fuel hydrogen combustion engines. Although the efficiency of these combustion engines is lower, designs are widely available as compared to the hydrogen fuel cell engine designs.

Whereas smaller vehicles (passenger cars, buses and trucks) are increasingly equipped with fuel cells, larger applications such as the use of e-H₂ in aviation, rail and shipping are still in the demonstration phase; this is necessary to show users that the technology works and is safe to use. In port areas, e-H₂ can also be used in mobile applications, such as reach stackers and forklifts, at terminals.

Hydrogen applications in mobility need to be demonstrated to develop the proper (engine) technology and human operation requirements. Demonstrations could serve to extend the development of the technology as well as reduce the cost of future installations. Furthermore, a rollout of e-H₂ in mobility requires an adequate refuelling infrastructure. Currently, the highest concentration of fuel cell vehicles and refuelling stations can be found in the USA, Western Europe and Japan⁶. As current energy hub, the port of Rotterdam, is a link between various energy processes and the mobility sector. Therefore, the port is undoubtedly suited to incorporate new forms of energy in the transport movements within and beyond its borders.

2.3. Integration with electricity system

Integrating hydrogen production with the electricity system and pipeline infrastructure is a key enabler for all possible uses of hydrogen, as hydrogen becomes a 'system carrier'⁷. Offshore wind power can thus be linked to on- or offshore electrolysis to produce green hydrogen. Integration of hydrogen into the electricity network allows for sustainable production and conversion of hydrogen, import/export of green hydrogen and full-scale use in all the sectors mentioned in this position paper. One of the challenges of integrating hydrogen in the electricity system is storage. Also, the electricity network cannot handle all electricity flow coming in from offshore wind farms in the future and upgrading the system is very expensive and a slow process. Therefore, conversion to and storage in the form of hydrogen is attractive. Hydrogen can be converted (back) into electricity and stored in batteries, it can also be stored in its gaseous and liquid forms or tied to other compounds (such as a liquid organic hydrogen carrier - LOHC). Much innovation is needed to solve the storage issue as this solution will be crucial to balancing the Dutch electricity network to account for seasonal changes and fluctuations in renewable electricity production.

Due to its location near offshore wind parks and its industrial cluster, the port of Rotterdam could become a large absorber of produced green hydrogen by applying it in various industrial processes. The port hereby forms a natural link between the electricity infrastructure and the hydrogen infrastructure and enables the national development of a hydrogen economy.

5 Lloyd's Register & UMAS, (2019), *Zero-Emission Vessels 2030. How do we get there?* [<https://www.lr.org/en/insights/global-marine-trends-2030/zero-emission-vessels-2030/>]

6 Shell, (2017), *The Future of Hydrogen*

[https://www.shell.com/energy-and-innovation/new-energies/hydrogen/_jcr_content/par/keybenefits_150847174/link.stream/1496312627865/6a3564d61b9aff43e087972db5212be68d1fb2e8/shell-h2-study-new.pdf]

7 TKI Nieuw Gas, (n.d.) [<https://www.topsectorenergie.nl/tki-nieuw-gas/waterstof>]

2.4. Heating the built environment

The application of hydrogen is also fitting into the plans of the Dutch government to reduce, and eventually even completely stop, the usage of gas for the heating of houses. Small-scale boilers, that burn hydrogen, could be used as a replacement for the current natural gas based boilers. Within the area of the port of Rotterdam, a pilot has started in a housing complex in Rozenburg where green hydrogen is produced in a local electrolysis facility and transported through pipelines of the former gas distribution network. The pilot does not only demonstrate the technical possibilities but also shows that hydrogen is a considerable alternative. Especially for households that are reluctant to the energy transition, acceptance of sustainable alternatives is essential for the encouragement of private investments.

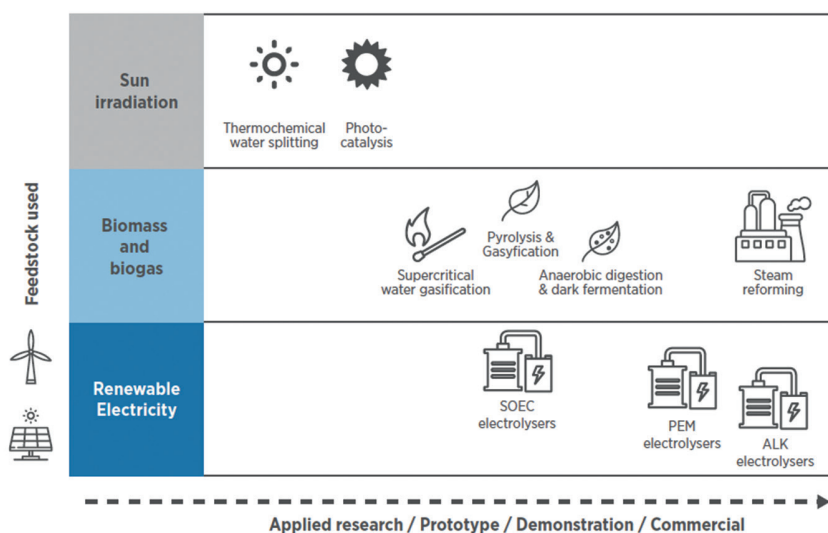
Figure 2. The hydrogen production unit at Rozenburg



3. DEVELOPMENT OF H₂ PRODUCTION TECHNOLOGIES: GREY, BLUE, OR GREEN HYDROGEN?

Hydrogen can be produced in various ways, all including different advantageous and disadvantageous characteristics of the specific production technology.

Figure 3. Maturity levels of hydrogen production options (IRENA), 2018⁸



As identified in figure 3, the technologies that are mature enough to be considered for commercial application are steam reforming and electrolysis. In order to understand the differences between these technologies, these will be elaborated on in this chapter. Currently, a lot of effort is being made to mature pyrolysis technologies by among others BASF, Shell, and TNO. The pyrolysis process consists of cracking methane into solid carbon and hydrogen whereby no CO₂ is emitted. This hydrogen production method could not only transform natural gas to hydrogen but could also be applied in bio-based and recycling processes. The developments concerning this technology should be kept track of but are not elaborated on in the proceedings of this chapter.

8 IRENA, (2019), Hydrogen from renewable power [https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2018/Sep/IRENA_Hydrogen_from_renewable_power_2018.pdf]

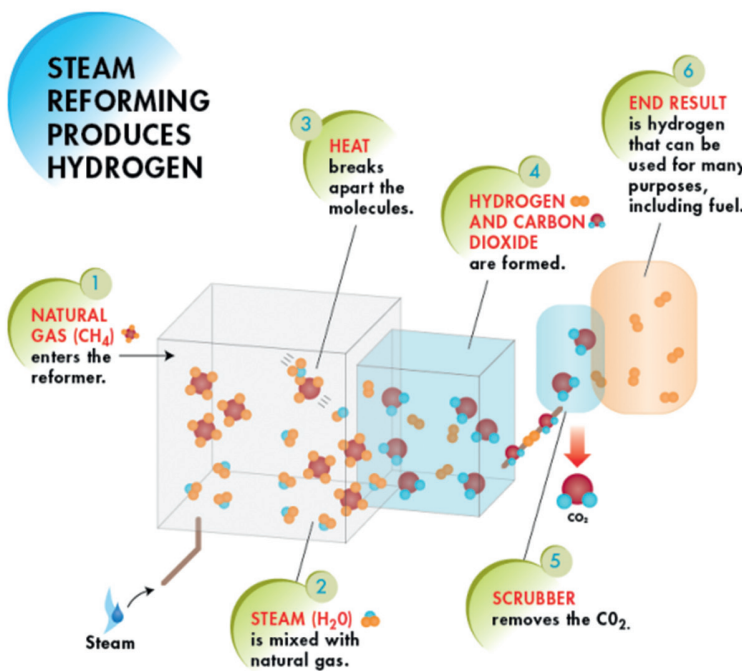
Table 1. Commercial hydrogen production options⁹

Energy source	Production technology	CO ₂ capture rate	Hydrogen purity level	Application
Green electricity	PEM electrolysis	not applicable	100%	Fuel cells Chemical processes Heating
	ALK electrolysis			
	SOFC electrolysis (high temperature, TRL 4)			
Natural gas	SMR (with or without CCS)	50-70%	99% (with additional processes)	Chemical processes Heating
	ATR (with or without CCS)	>90%	95%	Heating

3.1. Grey hydrogen

The current hydrogen production technology that is dominating the market is steam methane reforming (SMR). During the SMR process, natural gas and high temperature steam are transformed to a hydrogen rich gas mixture of hydrogen, carbon dioxide, and carbon monoxide. With current technologies it is possible to reach >95% hydrogen purity of this mixture. The purity level is high enough to apply the hydrogen in high temperature heating processes, but not high enough for the utilization of this gas mixture in chemical processes or fuel cells. Additional processes for purification could be considered to enable the latter two applications. Hydrogen that is currently used as a feedstock in chemical processes is mostly produced by a SMR plant and purified to a >99% purity level. Fuel cells require pure hydrogen inflow.

Figure 4a. Steam reforming process (Aalborg University, 2014)¹⁰



⁹ CE Delft, 2018, Feasibility Study into Blue Hydrogen. The conclusions of ATR vs. SMR technology (without additional engineering) mean more CO₂ certificates are needed when using SMR technology.

¹⁰ Aalborg University, (2014), Fuel cell and hydrogen technology [https://vbn.aau.dk/ws/portalfiles/portal/205441362/SummerSchool2014.pdf]

3.2. Blue hydrogen

Due to the fact that it is possible and feasible to capture the highly pure carbon dioxide outflow of the SMR process, adding carbon capture and storage (CCS) facilities to an SMR plant is considered to contribute to the transition to a sustainable hydrogen supply. The current so-called grey hydrogen production can be retrofitted by adding CCS-facilities and thereby turned into so-called blue hydrogen production. However, for the realization of a renewable hydrogen supply, the feedstock for hydrogen production needs to come from non fossil fuels. An alternative reforming method is the autothermal methane reforming (ATR) process. The processes differ in in- and output: ATR processes include an autonomous heating process and do therefore not need an external heat source and ATR processes are better suited for CCS because CO₂ is easier to separate in the output.

3.3. Green hydrogen

A promising sustainable alternative production method for the SMR process is the production of hydrogen through electrolysis. By separating water molecules with an electric current, 100% pure hydrogen (usable for all the identified applications) and oxygen molecules are created without emitting CO₂. In order to call this production method sustainable and produce so-called green hydrogen, green electricity from sources such as offshore wind parks in the North Sea needs to be fed into the electrolysis process. Two electrolysis technologies that are currently mature enough to be considered for large scale implementation are alkaline and PEM electrolyzers. The main difference between these two types of electrolyzers is the way they can deal with fluctuating electricity input. The intermittent character of renewable electricity sources requires electrolyzers to produce hydrogen while the fed in electricity is changing in quantity. Taking fluctuating loads into account, alkaline electrolyzers are perceived to be less favourable due to a decline of production efficiency. PEM electrolyzers, on the other hand, are able to maintain efficient production under these conditions.

For the production of large quantities of green hydrogen even larger quantities of green electricity need to be available. Moreover, the currently installed and planned green electricity generation capacity of the Netherlands is not sufficient for a complete transition to hydrogen. It is improbable that offshore wind parks in the North Sea can suffice in green electricity need for a full hydrogen transition. Import of green hydrogen from regions of the world that have a higher green electricity generation potential, such as the Sahara, is therefore considerable (see section 4 for more information).

Although green hydrogen will not be available in large quantities on the short term, a hydrogen infrastructure and market could be realized in advance. Blue hydrogen could thereby pave the road for green hydrogen by introducing hydrogen for several applications and incorporation hydrogen use in various processes. In order to incorporate the difference between grey, green, and blue hydrogen into business models, a certification system could be implemented that certifies green and blue hydrogen on the basis of their CO₂ reduction contribution¹¹.

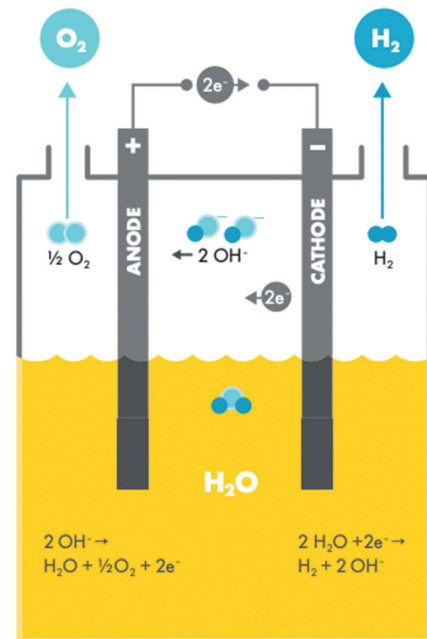


Figure 4b. Electrolysis process (Shell, 2017)

11 See also EU project CertifHy: [https://www.certifhy.eu/images/media/files/CertifHy_2_deliverables/CertifHy_Scheme-Dokument_V1-0_2019-03-11_endorsed.pdf].

4. THE PORT OF ROTTERDAM AS INTERNATIONAL HYDROGEN HUB

A practice that seamlessly fits the current function of the port of Rotterdam as transit port for energy carriers, is transforming the port to an international hydrogen hub. Hydrogen transport on a global scale is possible via sea vessels and trucks when hydrogen is liquefied, captured in ammonia, or carried by a hydrogen carrier. This latter option encompasses binding hydrogen to another molecule, transporting the carrier with the hydrogen, and then separating the carrier and hydrogen at the preferred destination. The feasibility of these technologies is still under consideration. Moreover, the development requires significant investments in terminals that are able to convert hydrogen in a portable form and vessels that are able to transport the substance. Infrastructure investments are needed to transport hydrogen from the hub in Rotterdam to other locations. Not only the companies within the port of Rotterdam but also German industrial companies could profit from the development of the international hydrogen hub. Many of these companies in the industrial cluster of Nordrhein-Westfalen, among which chemical and steel production companies, already consider the port of Rotterdam as their main provider of feedstock and energy.

Figure 5. Hydrogen transport vessel



A proposed design of a vessel transporting hydrogen to Japan. Japan aims at fuelling the Olympic Games of 2020 with green hydrogen that is produced in Australia.

[source: <https://enrg.io/japan-pushes-forward-hydrogen-society-ahead-olympics/>]

By importing green hydrogen from regions with a high renewable electricity generation potential, such as the desert, these regions could contribute to the energy transition globally¹². Regions with less potential will no longer be constrained by their geographic characteristics. Thus, the limits of offshore wind electricity generation on the North Sea will no longer constrain the development of the national green hydrogen economy. Furthermore, coordination of an international electricity grid and major investments in high voltage transmission lines could be avoided. Energy could be transported in the form of hydrogen and not electricity¹³. If the recent maturation of international LNG trade (also through the hub in Rotterdam) is indicative for potential growth, a hydrogen hub in the Port of Rotterdam could be the next big success. An issue to be considered however is the relatively high EU import tariff on hydrogen, which is currently set at 5%.

12 See also the Kalavasta HyChain project report of June 2019: [https://kalavasta.com/assets/reports/Kalavasta_HyChain_II_Report_FINAL_V1.1.pdf].

13 IEA, (2019), *The Future of Hydrogen and Provincie Zuid-Holland*, (2019), *Naar een groene waterstofeconomie in Zuid-Holland*.

5. INFRASTRUCTURAL NEEDS AND STORAGE POSSIBILITIES

In order to transport hydrogen, an extensive infrastructure will be needed. Due to the similar characteristics of natural gas and hydrogen gas, the natural gas infrastructure could be deployed for the transport of hydrogen, significantly reducing the initial investment costs of a switch to hydrogen. Of course, this requires a reduction of natural gas usage in order to free up the pipelines.

Figure 6. Hydrogen infrastructure of Air Liquide in North-Western Europe (AL, n.d.)



In the industrial cluster of the port of Rotterdam, a hydrogen infrastructure is already present. These networks are privately owned by the producers, Air Liquide and Air Products. Figure 6 shows the network of Air Liquide that connects the Rotterdam area with the port of Antwerp and the north of France. The producers balance supply and demand on the network by adjusting the production quantities of their SMR production plants and secure demand in long term contracts. Therefore, no storage capacity is currently needed within this hydrogen network. If the number of producers and consumers within the network increases and if hydrogen is deployed as a system carrier for the balancing of the electricity grid, the coordination of balance on the hydrogen grid will become more complex. Developing buffering capacity for adequate grid operation is then inevitable. The following options, ordered from small-scale to larger-scale, could be considered¹⁴:

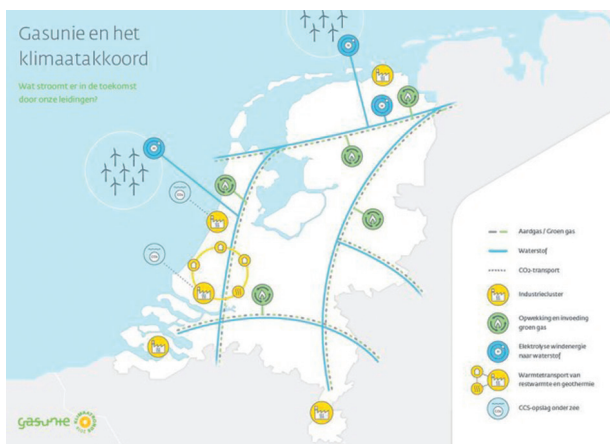
- **Line packing**, which is the process of adjusting pressure in the hydrogen pipelines and thereby changing the volume that is present within these pipelines. This method is widely used in the current natural gas network for the compensation of small daily variations. However, characteristics of hydrogen cause that storage possibilities via line packing are only one third compared to natural gas within the same grid. Furthermore, hydrogen pressure changes lead to higher deterioration of the pipes. Therefore, additional costs for reinforcements, maintenance, and replacement are inevitable. New hydrogen infrastructure could be designed to overcome these disadvantages, but then the possibility of reusing the natural gas infrastructure is dismissed.
- **Gaseous tanks** could also provide small-scale storage capacity. Daily fluctuations can be resolved using this storage method for small industrial processes. Larger-scale facilities are currently not feasible.

¹⁴ CE Delft, 2018, *Feasibility Study into Blue Hydrogen*.

- **Liquefied hydrogen** can be stored in cryogenic tanks after cooling hydrogen to -259.9 degree Celsius. Current technologies only provide small-scale liquefied hydrogen storage possibilities for daily fluctuations; technical development is needed to scale-up. Moreover, the cooling process requires significant amounts of energy and the tanks are relatively expensive. Another liquefied hydrogen storage method is binding hydrogen to a hydrogen carrier (LOHC). Recently, Vopak, the largest storage facilitator of the port of Rotterdam, invested in the further development of this technology (Hydrogenious).
- **Salt caverns** can be used as storage facilities for large volume of hydrogen and facilitate in daily balancing on a large scale and seasonal balancing. In the Netherlands, there are around 545 large salt caverns and 160 small large caverns that have a total estimated storage capacity of 100.000 to 300.000 cubic meter. Some of the caverns that are currently used for storing natural gas can be converted to hydrogen storage facilities. However, no caverns are in direct reach of the port of Rotterdam.
- **Gas fields** currently provide seasonal backup for the natural gas grid. Similarly to the salt caverns, the empty fields can be used to store hydrogen after conversion. It is currently unclear whether storage in the gas fields is feasible. Several offshore gas fields are located near the port of Rotterdam.

Taking into account the above options for storage, the only currently feasible possibility for long term storage is storage in a salt cavern. A hydrogen backbone, connecting the Rotterdam port area with the caverns in other parts of the Netherlands, could be realized to facilitate the needed storage. For Rotterdam, awaiting the realization of this backbone could slow down the development of a local hydrogen economy and the transition to an international hydrogen trade hub. Therefore, improvement of the technical readiness of liquefied hydrogen storage or gaseous hydrogen storage could make the port of Rotterdam less dependent on national plans and accelerate the local transition. Vopak is one of the companies in the port that is actively developing new hydrogen storage technologies, with partners such as Hydrogenious.

Figure 7. Hydrogen backbone 2030 projection (Gasunie, 2019)



6. PUBLIC AND PRIVATE INVESTMENT

6.1. Scaling-up technical applications

In order for the hydrogen economy to develop further, investment is needed in production facilities, infrastructure, storage facilities, and adaptation of processes such that hydrogen could be applied. The major issues regarding these investments are policy uncertainty and the feasibility of technologies. Due to the fact that investors are not assured of supporting policies, they await the right moment to invest. By waiting, investors hope that the technical readiness of the considered technologies for production and storage will increase and the investment costs will be reduced. However, this cost reduction will only occur when learning effects of realized projects can be incorporated.

A policy instrument that helps in overcoming the policy uncertainty is the 'Stimulerend Duurzame Energieproductie' (SDE) subsidy arrangement. This instrument secures the return on investment by defining a return that is acceptable for the investor and complements the return with subsidy to the agreed upon level when the market conditions do not fulfil the expected merits of the investment. Hereby, uncertainty regarding these merits is reduced and investments are incentivized. Moreover, the government can determine exactly which technologies the SDE instrument will be used. Innovation is hereby stimulated with focus. The government included hydrogen projects in the selection of projects that should be considered for the SDE subsidy, however, it is uncertain whether the next SDE will stimulate the development of green hydrogen¹⁵.

In order for learning effects to be realized and make technologies ready for a full system scale-up, pilots could be funded by public-private consortia. As mentioned before, mainly for the development of local storage facilities (section 5) and the adoption of hydrogen fuel cells in the mobility sector (section 2.2), such learning effects are necessary.

6.2. Infrastructure investments

The current electricity and gas infrastructure are operated by regulated grid operators that invest in needed infrastructure capacity. These operators are evaluated on their performance yearly and then allowed by the government to profit from their investment on a by the regulator determined level. For the hydrogen infrastructure, such a grid operator is not appointed (yet). Therefore, the current options for the development of an infrastructure are that (1) private parties invest in the infrastructure themselves; (2) appointing a grid operator that invests in the needed infrastructure; or (3) the government invests in a large-scale infrastructure that is sold to private parties or a grid operator in the future.

As mentioned before (section 5), realizing a hydrogen infrastructure could avoid large investments in the electricity infrastructure. While adapting a current natural gas pipeline to a 15 GW hydrogen pipeline approximately 25 - 50 million euros, the realization of a new high voltage electricity transmission line would cost about 100 - 200 times more. In order to investigate the possibilities of integrating the electricity and gas grid, Tennet, the current high voltage grid operator, made an infrastructure outlook¹⁶ together with Gasunie, the gas grid operator. These operators emphasize that investing in an integrated energy infrastructure requires a new regulatory framework.

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¹⁵ PBL, 2019, *Conceptadvies SDE++ 2020*. [https://www.pbl.nl/sites/default/files/cms/publicaties/pbl-2019_conceptadvies-sde-plus_plus_2020-verbreding-algemeen_3755.pdf].

¹⁶ TenneT & Gasunie, (2019), *Infrastructure Outlook 2050*. [https://www.tennet.eu/fileadmin/user_upload/Company/News/Dutch/2019/Infrastructure_Outlook_2050_appendices_190214.pdf].

7. A HYDROGEN TIMELINE

Although concrete national policies towards the development of a hydrogen economy are lacking, several steps can be derived from the plans of Rotterdam-Moerdijk cluster to reform the industrial cluster and its mobility sector¹⁷. Inspired by these plans, the following steps towards the hydrogen future could be taken:

1. Step 1: Increasing energy efficiency, development of infrastructure and CCUS (2019-2025)

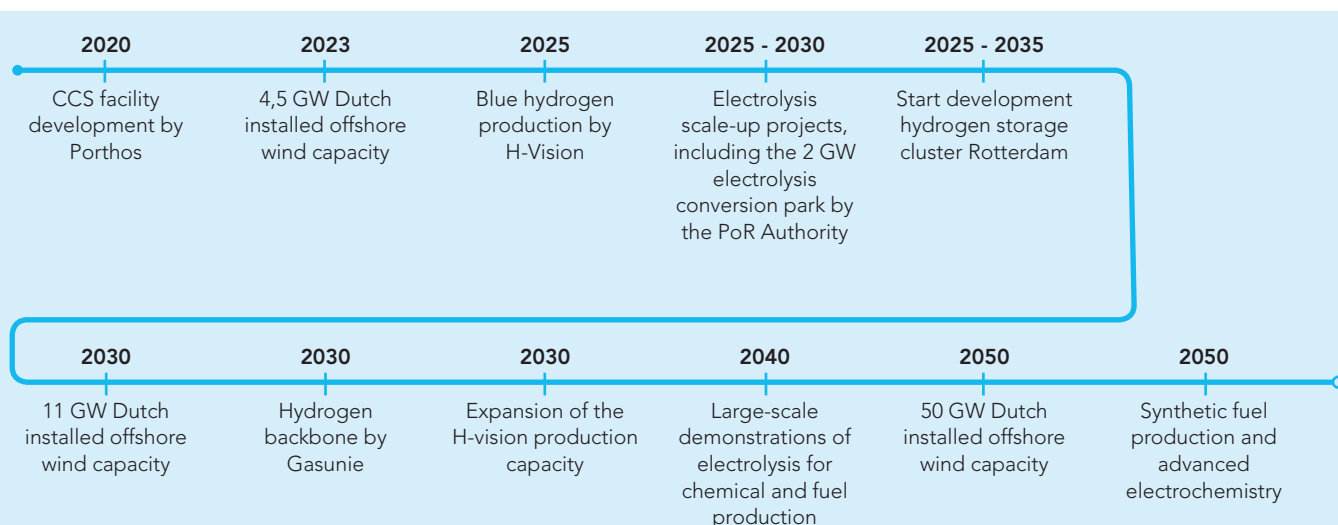
- Adapting laws and regulations and determining needed infrastructural changes
- Enabling of the production of blue hydrogen by the realization of a CCUS project (such as Porthos and H-Vision)
- Realizing a cost decrease for hydrogen storage (for example, by scaling up LOHC application)
- Starting up green hydrogen pilots in chemistry and mobility (such as the 250MW electrolysis project of BP, Nouryon, and the Port of Rotterdam Authority)¹⁸

2. Step 2: Developing a new energy system (2020-2030)

- Expanding the energy infrastructure for hydrogen (as suggested in the 2050 infrastructure outlook by TenneT and Gasunie)
- Scaling up blue hydrogen production
- Increasing the number of green hydrogen pilots (such as the 1 GW electrolysis project of the Port of Rotterdam Authority, ISPT, Deltalinqs¹⁹ and the development of the 2 GW conversion park by the Port of Rotterdam Authority linked to offshore wind parks located at the North Sea²⁰.)
- Increasing the number of hydrogen mobility pilots

3. Step 3: Renewal of raw materials and fuels system (2030-2050)

- Vast supply and use of green hydrogen in the industrial cluster
- Development of the international hydrogen hub
- Applying hydrogen in maritime transportation



The events on this timeline are indicative and based on the estimated final investment decisions as published by the various project leaders in their press releases. This timeline is thus not an indication or part of an actual political or investment agenda.

¹⁷ "In drie stappen naar een duurzaam industriecluster" (2018), [<https://www.portofrotterdam.com/sites/default/files/downloads/in-drie-stappen-naar-een-duurzaam-industriecluster-rotterdam-moerdijk-in-2050.pdf?token=SnEuvvqX>].

¹⁸ BP, (2019), BP, Nouryon en Havenbedrijf Rotterdam werken samen aan de studie naar groene waterstof. [https://www.bp.com/nl_nl/netherlands/home/nieuws/persberichten/bp-nouryon-en-havenbedrijf-rotterdam-werken-samen-aan-studie-naar-groene-waterstof.html].

¹⁹ Port of Rotterdam Authority, (2019), Startschot voor ontwerp gigawatt elektrolysefabriek, [<https://www.portofrotterdam.com/nl/nieuws-en-persberichten/startschot-voor-ontwerp-gigawatt-elektrolysefabriek>].

²⁰ Port of Rotterdam Authority, (2019), Havenbedrijf kijkt naar grootschalig waterstofproductie en netwerk. [<https://www.portofrotterdam.com/nl/nieuws-en-persberichten/havenbedrijf-kijkt-naar-grootschaliger-waterstofproductie-en-netwerk>].

8. CONCLUSIONS

The following key takeaways of this position paper are suggested as input for discussion in order to further stimulate the energy transition within the port of Rotterdam area:

Why now?

- The Dutch Climate Agreement and the extensive availability of new research and new projects show that hydrogen is a hot topic for the Dutch government, the industry, the mobility sector, and knowledge centres.
- Technologies for production and application are ready and various companies have tangible project proposals available for realization.

Why here?

- The port of Rotterdam, as industrial energy hub, in its proximity to offshore wind parks, and as a passing point for many transport movements, is an ideal location for integrated hydrogen solutions in various ways.
- As an international energy hub, the port of Rotterdam, is a connection to a possible international hydrogen market and thereby essential for the realization of a hydrogen economy on a national scale.

How to collaborate?

- To succeed, a system approach is necessary with collaboration across the whole chain.
- Not only national, but also international factors determine this development and should be monitored and anticipated by policymakers and companies in the port collectively.
- Sharing knowledge and insights with partners within the cluster is essential for keeping up with the international developments and securing a spot on the international stage.
- For the needed investments, private and public parties should communicate clearly in what they need and what they can provide to make this complex transition possible and to identify the blind spots that are currently restraining action. For example, the legal status of hydrogen infrastructure (public vs. private) is an issue that needs to be resolved.
- Collective investment and realization of pilots could stimulate learning effects and increase the technical readiness of various technologies. Financial instruments of the government, such as the SDE subsidy, should be tailored to the emerging hydrogen markets taking into account the implied system changes (i.e., systemic disruptions), begging the question whether these innovations can be evaluated using current system rules.

How to proceed?

- Demonstrations and pilots for electrolysis into green hydrogen (and advanced electrochemistry) should be started up in the port of Rotterdam region to prepare for eventual scale-up and the necessary system integration.
- As a passing point for many transport movements, the port is an ideal location for testing the application of hydrogen in the mobility sector. Pilots could point out the advantages for drivers, terminal operators, and shippers.
- The realization of a hydrogen backbone, connecting the port of Rotterdam to salt caverns in other parts of North-West Europe, could provide the needed energy security for industrial companies and substitute the need to expand expensive electricity infrastructure.
- By developing local storage facilities, the industrial actors within the port of Rotterdam could take precedence over national/European policies and start developing the foundations for the international hub that connects the national hydrogen market to the rest of the world.
- The optimal way and location to store hydrogen is as yet object of research and development and could be studied specifically for the situation present in the port of Rotterdam region.

SMARTPORT RESEARCH

This page summarizes key findings of past and current SmartPort research that is relevant for the development of a hydrogen economy. Project infographics are available on the SmartPort website (www.smart-port.nl) and further details can be requested at the SmartPort office.

Offshore wind capacity

- Offshore wind energy availability until 2035 is small compared to total energy demand in NL, so there will be competition for renewable electricity (project 'Wind at Sea' - TNO, 2018)
- Processes with the highest CO₂ output in the Rotterdam port area are refining (8,2Mton), steam cracker heating (1,4Mton), industrial gas production (1,4Mton) and chlorine production (1,2Mton) (project 'Wind at Sea' - TNO, 2018)

Absorption capacity & footprint reduction

- Developing green hydrogen is a no regret action for the industrial complex in Rotterdam (project 'Deep Decarbonisation Pathways' - Wuppertal Institut, 2016)
- Using green hydrogen in processes in the Rotterdam port area could potentially lead to a 13Mton CO₂ emissions reduction per year (3,8 ton CO₂ per ton H₂ if used instead of SMR and 9,8 ton CO₂ per ton H₂ if used as transport fuel) provided enough renewable electricity is available (project 'DDP Bottom-up' - TNO, 2017)
- Potential market absorption over 15 years for hydrogen is ±8 Mton/year in the Rotterdam port area (project 'DDP Bottom-up' - TNO, 2017)
- A 20MW electrolyzer used to produce hydrogen for refinery processes can reduce ±30 kton CO₂ per year (project 'Power-2-Gas-2-Refineries' - TNO, 2017)

Technological challenges

- Electrolysis technology needs scaling up to 1 GW (project 'Power-2-Gas-2-Refineries' - TNO, 2017)
- Closing the carbon cycle using carbon capture and usage requires green hydrogen for chemical processes (project 'CCU Landscaping' - Lux Research, 2017)
- Current industrial processes run continuously whereas renewable electricity is highly volatile - hydrogen can provide a means to balance the electricity network (project 'FlexI' - TUD, 2018-2021)
- Project 'Electrons to Chemicals' (2018-2021 - TNO, TUD) aims at scaling up (co-)electrolysis by developing two container-sized pilots in the Rotterdam port area for production of synthetic fuels and formic acid
- Project 'Electrons to Chemical Bonds' (2019-2023 - TUD, TU/e, RUL, WUR, RUG) looks at European sourcing of electrolyzer components and efficiency improvement of the electrolysis process
- Project 'Power-2-Fuels' (2019-2020 - TNO) analyzes the 'best' synthetic fuels options for heavy road transport, shipping and aviation
- Project 'e-THOR' (2019-2020 - TNO) will look at the integration of electrolysis at a site, including scale-up possibilities to 100 MW
- Project 'RELEASE' (2020-2025 - TUD) will work on efficiency of electrolysis technologies and provide system integration solutions

Organizational & policy challenges

- To reduce production costs of green hydrogen, changes in governance and (EU) policies and laws are required, especially in comparison to biofuels when used as a fuel (projects 'DDP Bottom-up' and 'Power-2-Gas-2-Refineries' - TNO, 2017)
- Proper balancing of the electricity network and organization of storage capacity could be done through an energy cooperative, under certain rules and conditions (project 'Rotterdam Energy Cooperative' - EUR, 2016)
- Experimental space for electrolysis and power-2-chemicals is needed and could be provided through a more flexible approach to the permitting and inspection regime (project 'Governance HIC' - EUR, TNO, 2019)



Position Paper

Rotterdam hydrogen hub

QUESTIONS?

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