Utilisation of green hydrogen and the implementation on a neighbourhood scale.

Research report

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The utilisation of green hydrogen and the implementation on a neighbourhood scale.

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In cooperation with:

Image 1 (background): Offshore windfarm (Nicholas Doherty, 2018)

Preface

My research report from my first work placement at BRO in Boxtel is in front of you. When I first started at BRO, but also at BUas, sustainability was a primary focus. Sustainability is a broad concept that can involve significant spatial considerations. How this could be translated into a specific spatial assignment became clear at BRO. BRO is engaged in the development of the energy transition and favours the use of a viable clean energy carrier such as hydrogen. Given the absence of comprehensible scientific information about hydrogen and the insufficient information about the implementation of green hydrogen into the built environment, a literature and case study is conducted for BRO. This provides a simplified explanation and an indication of the spatial adaptations that must be made when implementing hydrogen. This report is intended for employees of BRO.

My name is Feme Mijzen, and I am in my third year at BUas. I am currently enrolled in the International Spatial Development programme and have just completed my first work placement at BRO. I am very satisfied with my internship at BRO and the opportunity to combine my research with my work placement at this company. I'd like to thank my supervisor, Yvonne van Liebergen, in particular. Yvonne gave me the freedom, faith, and responsibility to carry out my research in my own manner. She encouraged and advised me on how to deliver a report that is useful for BRO and relevant to my studies. I am grateful for this pleasant collaboration and valuable learning experience.

Second, without Thomas Oorschot's guidance, I would not have achieved this result. His willingness to assist and his critical eye aided me greatly in completing this research report. I'd like to express my gratitude for your trust and pleasant cooperation.

My work placement has come to an end. I plan to continue my studies and apply everything I have learned.

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Explanatory list of words

Greenhouse gas	Gasses that are emitted during the combustion of fossil fuels
Climate mitigation	Efforts to reduce or prevent climate change
Energy transition	The energy sector's transition from a fossil-based system to sustainable energy
Off-take commitments	An agreement between a producer and consumer to purchase upcoming goods.
Sustainability	Prevention and avoidance of the depletion of natural resources to maintain ecological balance.
Heating transition	Transition in the built environment from natural gas heating to sustainable hydrogen heating.

List of Abbreviations

The EU	The European Union
HEAVENN	H2 Energy Applications in Valley Environments for Northern Netherlands
CCS	Carbon Capture and Storage
SMR	Steam Methane Reforming
SMR-CCS	Steam Methane Reforming – Carbon Capture and Storage
CO2	Carbon dioxide
H2	Hydrogen
CH4	Natural gas
H2O	Water
HNS	Hynetwork Services
FCH JU	Fuel Cells Hydrogen Joint Undertaking
GOS	Gas Delivery Station – Gasontvangststation
BUas	Breda University of Applied Sciences

Abstract

Globally, the use of energy represents by far the largest source of greenhouse gas emissions from human activities. Therefore, hydrogen is now widely regarded as one of the key energy solutions for the 21st century. However, the transition from a fossil fuel-based energy system to the implementation of a hydrogen-based energy system involves significant scientific, socio-economic, and technological challenges.
Given the shortfall of understandable scientific information about hydrogen, as well as information about the application of green hydrogen in the built environment, a literature and case study is conducted. This report aims to gain insight into the various types of hydrogen and assess and compare its implementation and utilisation on a neighbourhood scale. To achieve the research goal the research question that will be answered is: *“How can green hydrogen be utilised and implemented on a neighbourhood scale?”*

From this perspective, a comprehensive description of hydrogen is presented. Using an energy source, hydrogen can be separated from other elements. Then it can be used as a carrier of energy. When hydrogen recombines with oxygen, energy is released in the form of heat or electricity. Different types of hydrogen are distinguished by colour coordination:

- Grey hydrogen is the most commonly used process for producing hydrogen. Natural gas is used as a source of energy. As a result, hydrogen and CO_2 are produced as by-products, making this type of hydrogen high-CO_2.
- Blue hydrogen is created in the same way that grey hydrogen is, with the exception that CO_2 is captured and stored. If CO_2 is permanently stored, this type of hydrogen is low-CO_2.
- Green hydrogen is created with water and an electrolyser. The electrolyser separates hydrogen from oxygen. This process does not rely on fossil fuels and produces only water as a by-product. As a result, this type of hydrogen emits no CO_2 and is CO_2-free.

Furthermore, there are many new entrants, and there is a high demand for information, regulations, and investments. These requirements can be met by a few key stakeholders. These stakeholders can be found in the pilots and demonstration projects analysed in this report. To begin, the EU is investigating Hydrogen Valleys and intends to build fully functional hydrogen chains. HEAVENN and Europe's Hydrogen Hub are two projects from the Hydrogen Valley that have been analysed. Gasunie, the Port of Rotterdam, and the provinces of Friesland, Drenthe, and Groningen are all involved in these projects. Second, the Dutch government is working with Gasunie to build a transport network for hydrogen distribution. Lastly, the municipality of Hoogeveen is realising two hydrogen neighbourhoods.

This analysis has yielded findings and recommendations. According to the findings, the industry is the first to transition, and the spatial impact is minimal due to the already existing natural gas chain and transport network, which can be reused. National and regional adaptations will be more extensive. The design tasks at the neighbourhood level are minor because the adaptations are only within homes. Furthermore, some barriers were identified, and recommendations were made to address these barriers. The most significant barriers are the legislative and policy gaps, which the Dutch government should close. Funding should be obtained by initiating proactive dialogues and remaining open to potential project modifications to meet public funding requirements. Finally, green hydrogen should be made compatible with other fossil fuels, which requires investment from both public and private sectors.

Reading Guide

In this report is the utilisation of hydrogen and its implementation on a neighbourhood scale presented.

Chapter 1 establishes the context and the challenges are identified. Furthermore, it will be stated to whom the report is intended. The research model, questions, and method will be discussed.

Chapter 2 explains hydrogen in a comprehensible manner. Furthermore, the advantages and disadvantages are discussed.

Chapter 3 elaborates on the stakeholders of hydrogen on different levels such as international, national, regional, and municipal.

Chapter 4 provides an overview of projects currently taking place in the Netherlands at various levels, including national, regional, and neighbourhood. These projects' encounters are elaborated on.

Chapter 5 provides the conclusion and recommendations. The findings will be presented, and recommendations will be made based on them.

1. Introduction

1.1 Context

The quality of human life depends, among other things, on a reliable supply of energy. However, energy production and consumption place significant pressures on the environment. Energy production and consumption increase greenhouse gas emissions and air pollutant emissions. More so, it affects land use, waste generation, and oil spills, contributing to climate change, damaging natural ecosystems, and having adverse effects on human health (European Environment Agency, 2021).

In most countries the energy demand is still growing, including the Netherlands, and therefore still rely on fossil fuels (oil, gas, and coal) to meet energy demand. The combustion of fossil fuels keeps increasing atmospheric carbon dioxide (CO_2) concentrations, contributing to climate change and the increase in average global temperatures. Air pollutants are also released during energy activities, worsening the air quality (European Environment Agency, 2021).

Globally, the use of energy represents by far the largest source of greenhouse gas emissions from human activities (see figure 1). Two-thirds of global greenhouse gas emissions are linked to burning fossil fuels for energy to be used for heating, electricity, transport, and industry (European Environment Agency, 2021).

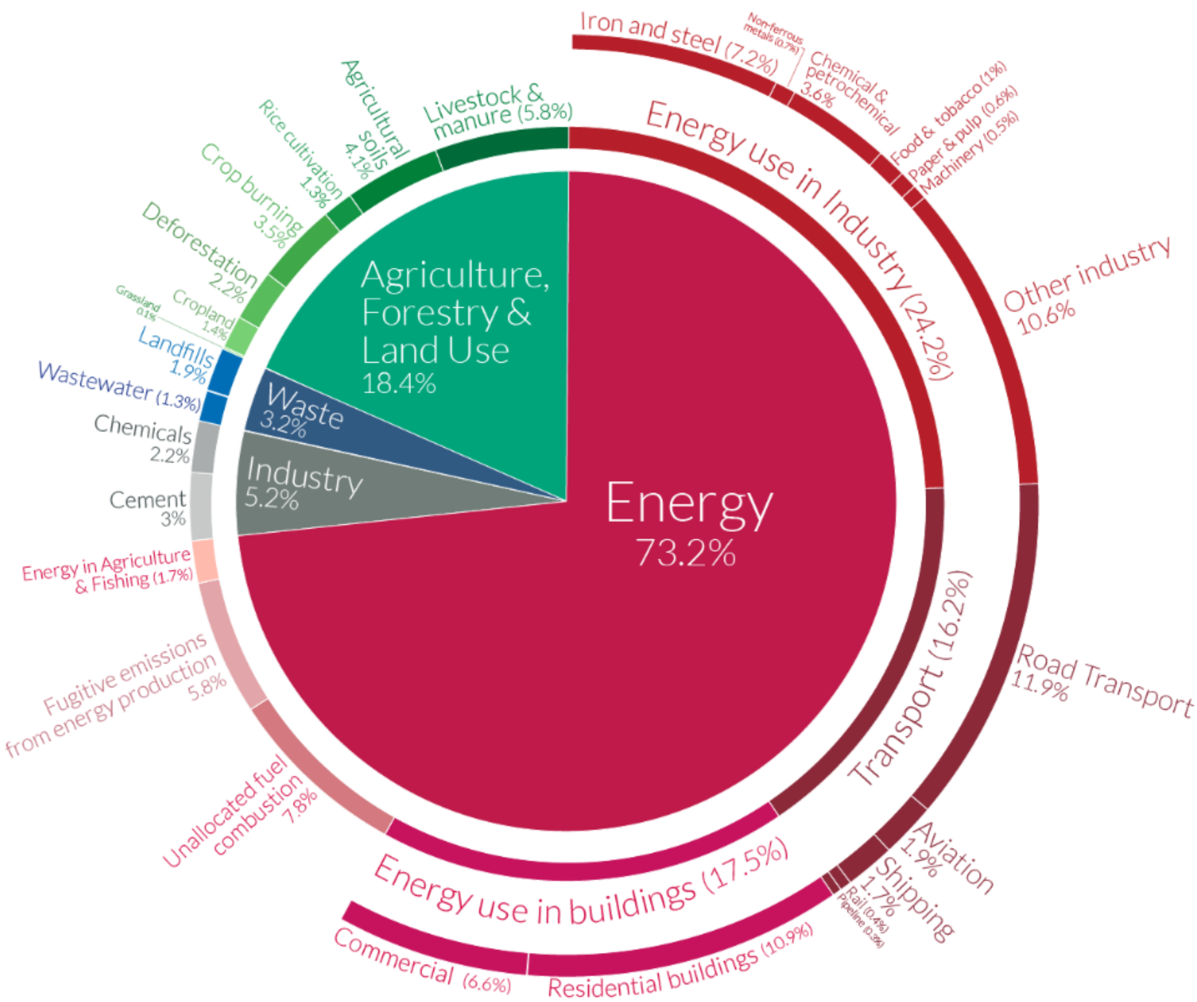

Figure 1: Infographic source greenhouse gas emissions (Richie, 2020)

Global efforts have been made to mitigate climate change. This is done in The Paris Climate Agreement in 2015. The Paris Climate Agreement was adopted by 195 countries and stated that global warming should be limited to 2 C° but the aim is to limit it to 1.5 C° (European Environment Agency, 2021). The National Climate Agreement in 2019 was made to reduce greenhouse gas emissions in the Netherlands endorsing climate neutrality for 2050 (Rijksoverheid, 2019). Moreover, the Dutch government has announced that it wants to be independent of Russian energy sources in 2023, due to the war in Ukraine that was initiated by Russia. Therefore, the intention exists that through a more sustainable energy supply, among other things, the import of Russian fossil fuels is stopped (RTLNieuws, 2022). This will contribute to the political urge regarding renewable energy.

There is an increase in greenhouse gas emissions at a time when they should be rapidly declining. With this understanding of the largest developer, a transition for effective solutions and mitigation strategies can be developed. However, that is a challenge. Hydrogen is now widely regarded as one of the key energy solutions for the 21st century. Hydrogen is becoming an increasingly viable clean, green option for the energy transition (Moradi & Groth, 2019). A technology such as hydrogen will contribute significantly to a reduction in environmental impact and the creation of new energy industries. However, the transition from a fossil fuel-based energy system to the implementation of a hydrogen-based energy system as a clean energy technology involves significant scientific, socio-economic and technological challenges (Edwards et al., 2008).

BRO is a spatial planning consultancy and design firm. They assist governments, entrepreneurs, social organisations, and individuals with spatial issues and in the realisation of ideas. Energy transition projects are often seen within this business. These are projects dedicated to the CCS technique; this is an important development for sustainable hydrogen, but it will be discussed further in chapter two. Another example of such a project is the connection of offshore wind farms to the power grid. This report presents research on the simplified explanation of hydrogen as well as pilot and demonstration projects taking place in the Netherlands. This illustrates the use of green hydrogen in industry and the built environment.

1.2 Research method

Given the insufficient comprehensible scientific information about hydrogen and insufficient information about the implementation of green hydrogen into the built environment, a literature and case study is conducted to help answer the research question. The research question is as follows: “How can green hydrogen be utilised and implemented on a neighbourhood scale?” The objective of the research is to gain insight into the various types of hydrogen and assess and compare its implementation and utilisation on a neighbourhood scale.

The materials analysed are reports about hydrogen and reports regarding pilots and demonstration projects of hydrogen application in the built environment. It is important to emphasise the use of two documents. Two letters to parliament appear frequently in this report. First, a letter to parliament from 2020 in which Minister Wiebes informs the second chamber of the Dutch government's hydrogen vision. Second, in 2022, Minister Jetten informs the second chamber about the development of the transport network. This secondary data is used to produce contextual and real-life knowledge about the topic of hydrogen and hydrogen implementation in the built environment. After which it is narrowed down to neighbourhood scale. The built environment must be analysed on multiple levels to incorporate all spatial adaptations that are of importance.

This resulted in findings and a recommendation regarding the implementation of green hydrogen.

1.3 Objective

Much is already known about hydrogen itself. However, the available literature is often very technical. Furthermore, little is known about the incorporation of hydrogen into spatial policy and the built environment.

This report aims to gain insight into the various types of hydrogen and assess and compare its implementation and utilisation on a neighbourhood scale.
The objectives are to describe and explain green hydrogen and assess the case studies of its implementation at national level. The research highlights three aspects:

- primarily, a description of the various types of hydrogen will be provided and the (dis)advantages of the relevant hydrogen type will be presented;
- secondly, a description of the government's interest will be brought forward;
- finally, examples of green hydrogen implementation in neighbourhoods will be provided.

1.4 Questions

The main question must be answered to achieve the research objectives. The primary question to be addressed during this study is:

"How can green hydrogen be utilised and implemented on a neighbourhood scale?"

The sub-questions listed below provide context for answering the main question:

- What are the characteristics of hydrogen and why is it necessary to optimise the utilisation?

- Why is hydrogen utilisation of interest to public and private organisations and why should they pay attention to hydrogen utilisation as part of future plans and visions?

- Which public and/or private organisations currently work with hydrogen, what is their vision and what do they encounter?

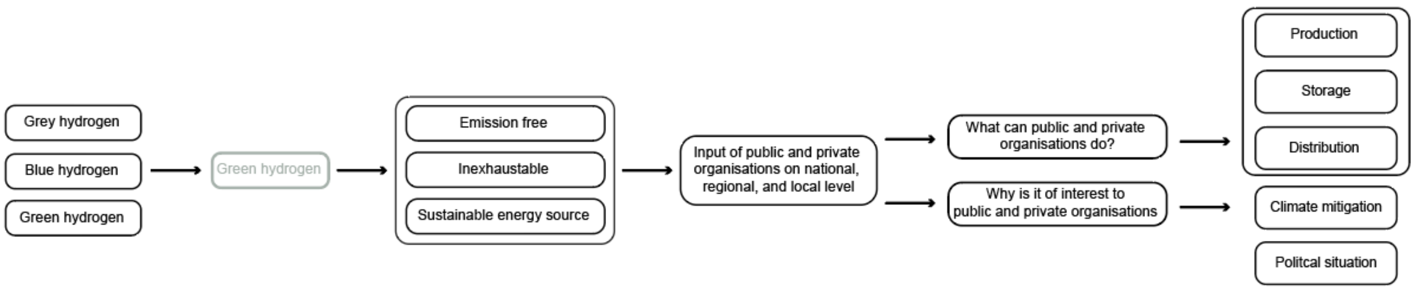

Figure 2: Research model

For this research, a research model has been composed (see figure 2). Showing the intent of the research will lead to the context that will address the main research question.

The content is divided into three sub-research questions. The first sub-research question addresses the characteristics of hydrogen and the benefits of green hydrogen utilisation. The advantages and disadvantages of green hydrogen will also be elaborated on. This provides a foundation for answering the following sub-research questions.

The next step in the research process will be to determine the interest of public and private organisations in green hydrogen, why it is beneficial for them to utilise green hydrogen, and what they can do to help regarding the implementation on a neighbourhood scale. This is important to address since there are multiple important public and private organisations that are important stakeholders. The steps mentioned above will be researched through literature studies.

After this inventory, pilots and demonstration projects will be analysed to see what project initiators have encountered when they implement green hydrogen. This will concern both advantages and disadvantages of the implementation.

Based on the information gathered from the literature and case studies, an analysis of green hydrogen utilisation is provided and an advice and a conclusion can be given regarding the implementation of hydrogen on a neighbourhood scale.

2. Hydrogen

As stated in a letter to parliament by Minister Wiebes in 2020, a sustainable energy system that is viable, reliable, clean, affordable, safe, and spatially suitable, CO_2-free gasses are indispensable. CO_2-free hydrogen is a required link to meet the climate goals established in the National Climate Agreement. He recognises the ambitions and projects that are initiated by several public and private organisations on macro, meso, and micro levels. As confirmed by the NOS op 3 in 2020 hydrogen is currently being researched on (inter)national level as an alternative energy carrier and fuel resource. This chapter will provide a comprehensive explanation of grey, blue, and green hydrogen and its production. Additionally, the (dis)advantages of green hydrogen in particular will be discussed.

2.1 Types of hydrogen

Hydrogen is the lightest, smallest, and most common element on the planet. It is colourless, tasteless, odourless, and non-toxic. Hydrogen (H_2) does not exist independently on earth but always exists in combination with other elements. This could be, for example, water (H_2O) or methane (CH_4). As a result, hydrogen must always be separated from another element if it is used as an energy carrier. To do so, another energy source is necessary. Hydrogen then exists as a gas, increasing pressure to around 700 bar can reduce hydrogen volume but it can also be liquefied at temperatures as low as -253 °C. This is beneficial for the transporting possibilities of hydrogen (Newborough & Cooley, 2021).

It is critical to note that hydrogen is not an energy source; instead, it is an energy carrier. Hydrogen is capable of transporting tremendous amounts of energy. Once hydrogen and oxygen recombine, energy is released as heat or electricity. Hydrogen is very energy intensive, about three times more than natural gas (Newborough & Cooley, 2021).

As stated previously, to generate hydrogen, an energy source is required. The type of hydrogen produced is determined by the type of energy used. Colour coordination is used in the energy industry to differentiate between various types of hydrogen (see figures 3, 4, and 5). Different colours are assigned to the hydrogen depending on the type of production used. However, there is no universal naming convention, and colour definitions can change over time and even across countries. Conventional high-CO_2, low-CO_2, and CO_2-free production routes are referred to as grey, blue, and green, which will be explained in this chapter, since these are most commonly used currently or are most relevant for the future (Hermesmann & Müller, 2022).

2.1.1 Grey hydrogen

Steam Methane Reforming (SMR) is the most frequently applied process to produce hydrogen today. Natural gas is used as an energy source. Natural gas consists of the biggest part of methane (CH_4). In the presence of steam (H_2O), at temperatures of 700-900 C° and pressures of 3-35 bar this chemical reaction results in CO_2 and hydrogen (H_2). The hydrogen is used and the CO_2 is released into the atmosphere as a by-product (Hermesmann & Müller, 2022).

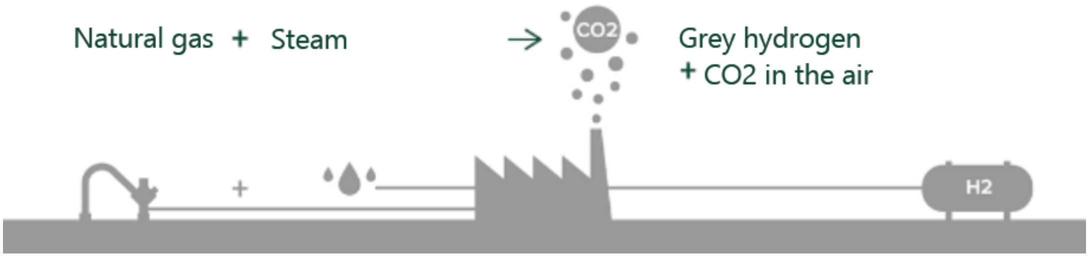

Figure 3: Grey hydrogen (Milieu Centraal, n.d.)

2.1.2 Blue hydrogen

Carbon Capture and Storage (CCS) is a technology that is currently under development and is a promising way to reduce process-related CO_2. Blue hydrogen is produced through the SMR-CCS approach. It is based on the same production process and energy source as grey hydrogen from SMR. Instead of releasing CO_2 into the atmosphere as a by-product, it gets captured and stored. The captured CO_2 can be stored in empty underground gas fields. If the captured CO_2 is stored permanently the blue hydrogen can be referred to as low- CO_2 (Hermesmann & Müller, 2022). Capturing 100% of the CO_2 through the CCS technique is not possible, it will more likely be 90% of the CO_2 emissions that will be captured and stored eventually (Hoogervorst, 2020). Blue hydrogen is therefore best to implement during the transition to limit the emissions but over time transition to green hydrogen completely.

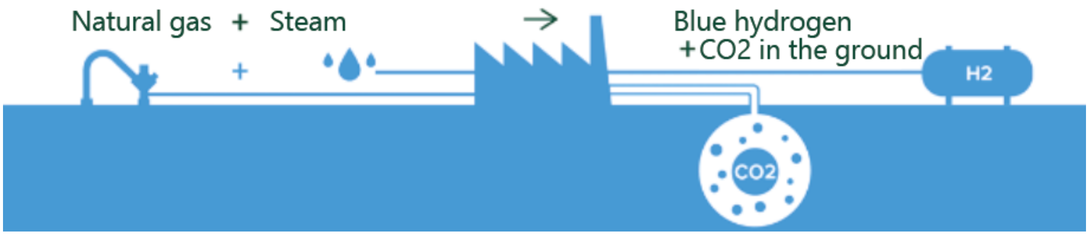

Figure 4: Blue hydrogen (Milieu Centraal, n.d.)

2.1.3 Green hydrogen

Water electrolysis is the process of using electricity to split water (H_2O) into hydrogen (H_2) and oxygen (O_2). The electricity used is generated sustainably, through utilising solar or wind power. In contrast to other technologies, water electrolysis is not relying on fossil fuels nor is the process releasing emissions (Hermesmann & Müller, 2022). The only by-product of green hydrogen is water. The water that is consumed during electrolysis is reproduced when the hydrogen is oxidised (Newborough & Cooley, 2021). This makes green hydrogen an interesting energy carrier to reduce the emission of greenhouse gasses. Therefore, this research report will continue to assess green hydrogen and its implementation.

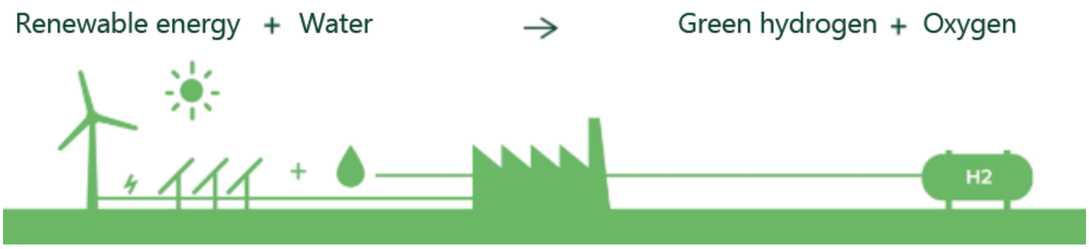

Figure 5: Green hydrogen (Milieu Centraal, n.d.)

2.2 Advantages and disadvantages of green hydrogen

This paragraph will mention the advantages and disadvantages of green hydrogen and green hydrogen utilisation. Weighing up the (dis)advantages can improve the understanding of the situation and encourages an objective approach towards forming an opinion. This paragraph will show the motive behind the energy transition to green hydrogen but also the encounters. These encounters are not unconquerable, and they are not researched further in this report because they can be stand-alone research. These encounters, however, are particularly important to mention to highlight obstacles in the process. In sub-paragraph 2.2.1 the advantages of green hydrogen are described (see table 1). In sub-paragraph 2.2.2 the disadvantages of green hydrogen are described (see table 2).

2.2.1 Advantages

Table 1: Advantages of green hydrogen

Advantages	
Making polluting sectors more sustainable	It can be widely used in industry. It is also an ideal choice for long-distance travel by planes, ships, and trucks. It enables polluting industries in becoming more sustainable (Haverkort, 2021).
Sustainable storage	Store hydrogen in the form of hydrogen in tanks. This is preferable to storing energy in batteries. For long-term storage, batteries are expensive, big, and polluting. Hydrogen is then a good alternative for seasonal storage (Haverkort, 2021).
Minor adaptations	Through hydrogen utilisation existing gas pipelines can be reused, requiring only the replacement of the central heating boiler and gas stove. These adaptations are minor and manageable (Haverkort, 2021).
Sustainable by-product	Water is only produced as a by-product of hydrogen. Because the water used to produce hydrogen is reproduced when oxidised, it does not contribute to water scarcity and does not emit CO_2 (Newborough & Cooley, 2021).

2.2.2 Disadvantages

Table 2: Disadvantages of green hydrogen

Disadvantages	
Losing a lot of energy	When creating hydrogen from water, you lose a lot of energy; a quarter of the energy is used for heat. Hydrogen is kept under extreme pressure to avoid having to build massive tanks. A significant amount of energy is also lost. You will eventually be left with a quarter to a third of the original energy.
Low availability of green hydrogen	At the moment, only a small portion of hydrogen is green. As a result, extracting hydrogen from natural gas is less expensive. On days when the wind is strong or the sun is shining brightly and there is excess electricity, you could turn it to hydrogen.
Green hydrogen is expensive	Hydrogen is still relatively expensive at the moment. However, as technology advances, it will only become cheaper (Haverkort, 2021). The first green hydrogen production installations are relatively small, and they are

	being realised in industry sectors where the demand is already relatively high due to the industry's reliance on grey hydrogen. Upscaling production installations will eventually contribute to cost reductions. (Ministry of Economic Affairs and Climate, 2020).
Distrustful about hydrogen utilisation	The safety risks of hydrogen are related to its use under high pressure, the fact that hydrogen ignites relatively quickly, and its proclivity to leak. However, because hydrogen is very light, which causes it to leak faster, it is also advantageous because it can be deflated quickly in the event of calamities (WaterstofNet, n.d.). Energy use always poses safety risks, including the energy sources we are currently using. Hydrogen is not more dangerous than current energy sources (Weeda & Niessink, 2020). As mentioned previously, there is already abundant experience in safely and responsibly handling hydrogen.

2.3 Conclusion

To summarise, hydrogen is an energy carrier that can transport tremendous amounts of energy. There are three types of hydrogen: grey (high-CO_2), blue (low-CO_2), and green (CO_2-free).
The benefits are that green hydrogen is extremely sustainable, only produces water as a by-product, can improve sustainability in polluting sectors such as industry and heavy transport, and the adaptations required to distribute green hydrogen to homes and within are minor and easily manageable.
The disadvantages are that a lot of energy gets lost during production, there is low availability of green hydrogen which also makes it more expensive, and people are having safety concerns. Nevertheless, with today's innovations and the never-ending technical exploration, there lies an opportunity in resolving these issues.

3. The stakeholders of hydrogen

Hydrogen is developing quickly. The system around hydrogen and the network of persons and organisations which are concerned with hydrogen grows rapidly. The challenge to initiate a sustainable hydrogen chain is complex. There are many new entrants and the need for information is high. Demand, supply, storage, and infrastructure have to be developed and there are vast dependencies between them. Businesses that are considering using sustainable hydrogen as an energy carrier need an estimate of future prices. Moreover, it is important to understand who will operate the network and how high the transport rates will be. Potential investors in production capacity require information about demand development. Infrastructure development is linked to supply-demand dynamics. Furthermore, changes in demand, supply, storage, and infrastructure are heavily influenced by government policy. (Ministry of Economic Affairs and Climate, 2020).

When green hydrogen is implemented in the built environment it is important to look at the different levels that apply and the significant number of stakeholders which are involved. The different levels and stakeholders are divided into international, national, regional, and municipal/neighbourhood levels. These levels and stakeholders are analysed and discussed in this chapter.

3.1 International

Deploying hydrogen in Europe faces challenges that neither the private sector nor member states of the EU can address alone. Developing a hydrogen chain past the tipping point needs critical mass investment, an enabling regulatory framework, new lead markets, and sustained research and innovation into breakthrough technologies. Bringing new solutions to the market and a large-scale infrastructure network are examples of input that only the EU and the single market can offer. Only in an international context cost reductions can be realised (European Commission, 2020).

When looking at the large-scale infrastructure network and how the Netherlands participates in this. It is of strategic importance for ports, particularly the port of Rotterdam, to maintain their current hub function for international energy flows. It carries huge benefits for the Netherlands to be the hub of a hydrogen chain and deploy current infrastructure. The development of the European sustainable hydrogen market is therefore also crucial for the development of the Dutch sustainable hydrogen market. For example, developments in Germany are significant to the Netherlands because it is likely that a great part of German demand will have to be met by imports entering Europe through the port of Rotterdam. (Ministry of Economic Affairs and Climate, 2020).

North-western Europe is expected to have high demand because renewable energy cannot be generated as inexpensively or on such a large scale as it can in other regions such as the Middle East, North Africa, and, more recently, Spain and Portugal. Exporting hydrogen is a strategy to implement hydrogen. The opportunity to build an export sector grows in regions where renewable electricity can be generated inexpensively and on a large scale (Ministry of Economic Affairs and Climate, 2020).

3.2 National

The introduction of a new energy carrier is complex and will take decades; the Dutch government must take the initiative in this regard. The central government will have to establish a framework, as well as define and enable powers and obligations (Weeda & Niessink, 2020). For example, the costs of producing sustainable hydrogen must be reduced. Upscaling production installations is an effective instrument. In the long run, seasonal storage in vacant underground salt caverns will be required. Furthermore, infrastructure and storage capacity preparations should be carried out. The Dutch government should operate technical boundaries and have a policy framework capable of facilitating ambitious plans (Ministry of Economic Affairs and Climate, 2020).

The Dutch government sends a signal when it presents an ambitious policy agenda and takes critical steps to realise infrastructure and other preconditions. This is critical for businesses that have announced projects in the Netherlands. As a result, these businesses can begin using sustainable hydrogen sooner, and regions and sectors such as industry, mobility, and the built environment can begin their energy strategies and first pilots and demonstrations. As a result, the dynamic displayed in the Netherlands will be recognised internationally, broadening the appeal of the Dutch business climate (Ministry of Economic Affairs and Climate, 2020).

3.3 Regional

Regions play a crucial role in the expansion of sustainable hydrogen. Northern Netherlands, with provinces like Drenthe, Groningen, and Friesland, is an example of a region where, based on existing infrastructure and knowledge of gas, a new economic perspective is being developed. Regional authorities and organisations are essential in developing and facilitating local infrastructure and projects in the built environment, mobility, and industry (Ministry of Economic Affairs and Climate, 2020). Electrolysis, storage, and import projects will not be possible without a fully functional infrastructure (Ministry of Economic Affairs and Climate, 2022). Actively demonstrating and recognising the possibilities helps establish a social support base for hydrogen and residents' involvement in the energy transition (Ministry of Economic Affairs and Climate, 2020).

Regional network operators must also be included. To determine whether the existing gas network can be used for sustainable hydrogen transportation and distribution, research must be conducted in collaboration with network operators such as Gasunie. The transport network will be reused in a functioning hydrogen chain and will most likely be operated by Gasunie, as they currently own the Dutch transport network. Network operators must gain experience in hydrogen transportation and distribution. Network operators will collaborate with market participants to launch hydrogen pilots to gain insight into a functioning hydrogen chain. As a result, future hydrogen market networks may be both public and private (Ministry of Economic Affairs and Climate, 2020).

3.4 Municipal – neighbourhood

The municipality is an important player in the heating transition. A municipality can decide whether and when to transition neighbourhoods from natural gas to sustainable hydrogen. However, the Dutch government could force such a transition. Furthermore, it is the responsibility of municipalities to discuss such transitions with stakeholders such as residents and property owners, as well as conduct the necessary research to make an informed decision. Eventually, municipalities will be in charge of issuing permits and establishing installations for decentralised hydrogen production and storage. This transition will not occur all at once; rather, it will occur per spatial unity (Weeda & Niessink, 2020).

Moreover, residents have to make their homes hydrogen-proof. It requires an inventory of their homes and installations and if necessary some minor adaptations. For example, residents would need to replace boilers and shift to induction cooking. These adaptations can likely be covered by a housing cooperative. Besides these minor adaptations, residents will notice little about the transition (Weeda & Niessink, 2020).

Also on a smaller scale, but significant for sustainable hydrogen development is the agricultural sector. This sector offers opportunities for generating and utilising hydrogen. Agricultural holdings have a lot of space for generating renewable energy which can then be used for generating green hydrogen. Moreover, the utilisation of green hydrogen offers a sustainable solution to utilising agricultural machinery, tractors, and heavy agricultural transport. The agricultural businesses could work together and focus on pilots (Ministry of Economic Affairs and Climate, 2020).

Hydrogen has the potential to be applied in the built environment. To organise the safe utilisation of hydrogen in the built environment and gain knowledge as much as possible, pilots will be set up from 2020 through 2025. (Ministry of Economic Affairs and Climate, 2020). Examples of such projects are discussed in chapter four.

3.5 Conclusion

To summarise, grey hydrogen is already used in the industry and provides an economic foundation and infrastructure for green hydrogen. The EU has ambitions to utilise green hydrogen and the northern Netherlands is going to play a huge role in this development. If a green hydrogen-based economy is to be developed, the industry should shift to green hydrogen utilisation, and sectoral integration to mobility and the built environment is critical. Each level must provide input, and these levels cannot deploy green hydrogen without each other. EU member states, for example, need the EU for large-scale investments and a large-scale infrastructure network. The Dutch government must assist in reducing production costs, establishing a realistic but ambitious policy framework, maintaining a hub function for the port of Rotterdam, and making it appealing for businesses to start investing. Regional network operators and regional authorities are critical in the development and facilitation of local infrastructure. Municipalities are important because they have direct contact with key stakeholders such as residents, agricultural holdings, and property owners. Municipalities will be in charge of issuing permits and establishing installations of decentralised hydrogen production and storage facilities. The Netherlands has many stakeholders, and if the Netherlands takes an active role in developing a green hydrogen market, the Netherlands can reap significant economic benefits.

4. Examples

Grey hydrogen is already widely produced and used in the Dutch industry today. The Netherlands even leads in the production of grey hydrogen, with significant CO_2 emissions. As a result, there is already a lot of experience in safely and responsibly handling hydrogen. Because there is already an economic foundation and infrastructure for grey hydrogen, blue or green hydrogen should be able to easily take its place in this system. The industry's existing grey hydrogen chain must become more sustainable, and the industry could eventually serve as a foundation for the transition to green hydrogen in the built environment (Ministry of Economic Affairs and Climate, 2020).

Hydrogen is indispensable to industrial sectors and ports and their strategy for a sustainable future. The mobility sector is dependent on hydrogen to achieve zero-emission transportation. Within regions such as the northern Netherlands, hydrogen clusters are being developed. On a smaller scale, municipalities, residents, network operators, agricultural holdings, and middle to small businesses are attempting to implement hydrogen (Ministry of Economic Affairs and Climate, 2020).

Local strategies are being developed and are being linked to economic opportunities. This is an essential part of jointly shaping the energy transition. The deployment of sustainable hydrogen in the Netherlands creates new job opportunities, improves air quality, and is essential for the energy transition (Ministry of Economic Affairs and Climate, 2020).

As described in chapter three, pilots are being established and a large number of developments are taking place in the Netherlands between 2020 and 2025 to organise the safe use of hydrogen in the built environment and gain as much knowledge as possible. Some of these developments and pilots will be presented in this chapter. National, regional and local each has a pilot or development to exemplify how the implementation and utilisation of sustainable hydrogen impact the built environment on that level.

4.1 Development of the transport network for sustainable hydrogen

The development of the gas pipeline transport network is a national development. However, this transport network, also known as the backbone, is extremely important for all developments in Northwest Europe. Throughout this chapter, the transport network will be seen in various projects that are also being analysed. As a result, it is critical to first explain this development.

The transportation network connects industrial clusters and regions, ports, offshore wind farm landing points, storage facilities, and neighbouring countries by reusing and constructing new infrastructure. Hynetwork Services (HNS) will develop and manage the transport network. HNS is a subsidiary of Gasunie. HNS will be assigned as the network operator. The Dutch government has set aside a maximum of €750 million for transport network development. There are risks to investing in energy infrastructure while it is still being developed. Waiting, on the other hand, is not an option because without connecting infrastructure the electrolyses, storage, and import projects will not be realised (Ministry of Economic Affairs and Climate, 2022).

The Dutch government has made a roll-out plan for the development of the transport network which results in three phases:

Phase 1 – 2025-2026

The aim, for now, is the realisation of a transport network that goes into the big industrial clusters, connects them and provides access to storage facilities, and connects the Netherlands with neighbouring countries. Because the industrial clusters along the coast are expected to have the highest demand for transport capacity, these would also be the industrial clusters where electrolysers will produce green hydrogen due to offshore wind farms. Where grey hydrogen is produced currently blue hydrogen can be produced and where there are possibilities for CCS. When volumes get bigger, storage is necessary and exchange between clusters will rise. Therefore, the connection between clusters will also have to be made possible. Import and transit to Germany are accounted for in the first phase. A need for interconnection with Belgium can also rise in the first phase and also has been accounted for (see figure 6).

With a transport network, the Netherlands can facilitate these energy flows and position the Dutch ports internationally. These flows are not only beneficial for the Dutch economy but will also contribute to the financing of the transport network (Ministry of Economic Affairs and Climate, 2022).

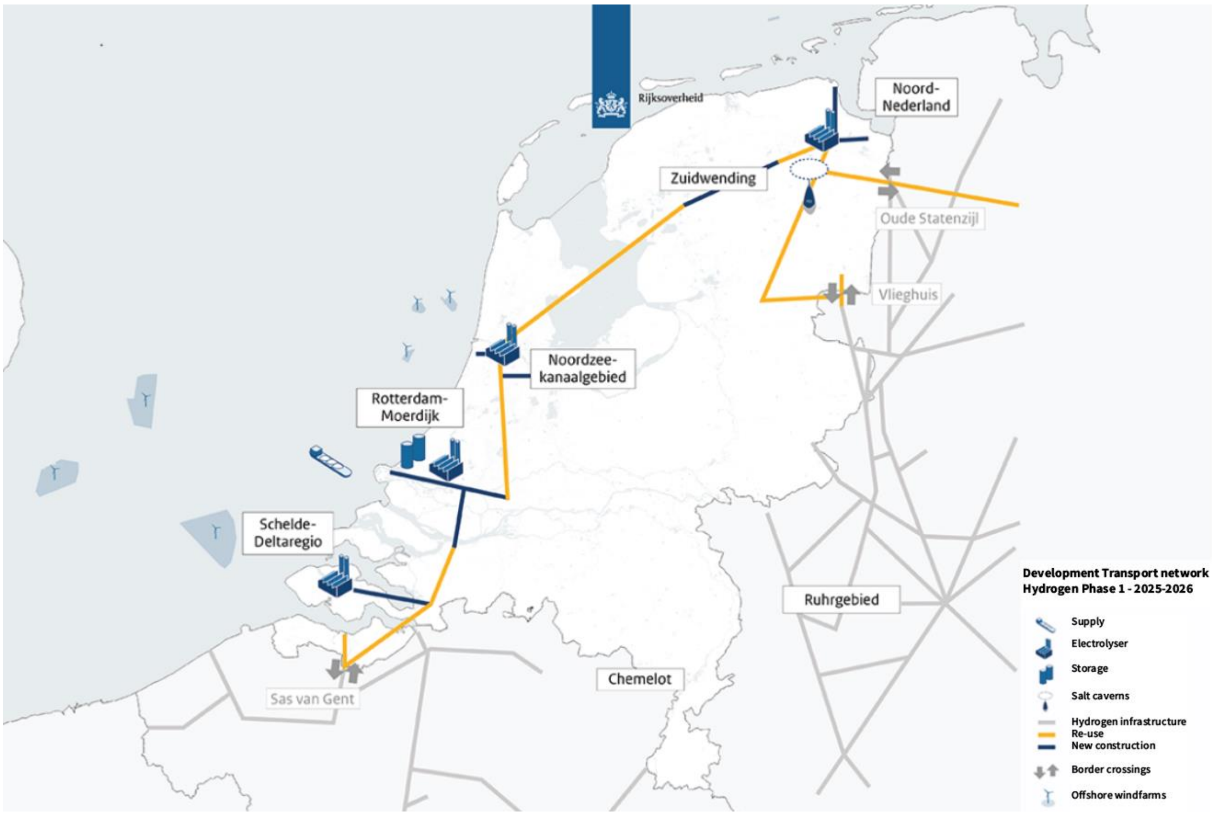

Figure 6: Phase 1 (Ministry of Economic Affairs and Climate, 2022)

Phase 2 – 2027-2028

Demand from other parts of the Netherlands, such as Limburg, Chemelot (see figure 7) and other industrial clusters spread across the country, should be met by industrial clusters along the coast. This indicates that a link between coastal and inland industrial clusters must be established. The phasing is affected by the interest of businesses in utilising the transport network. The second phase aims to connect every industrial cluster and establish connections with neighbouring countries (Ministry of Economic Affairs and Climate, 2022).

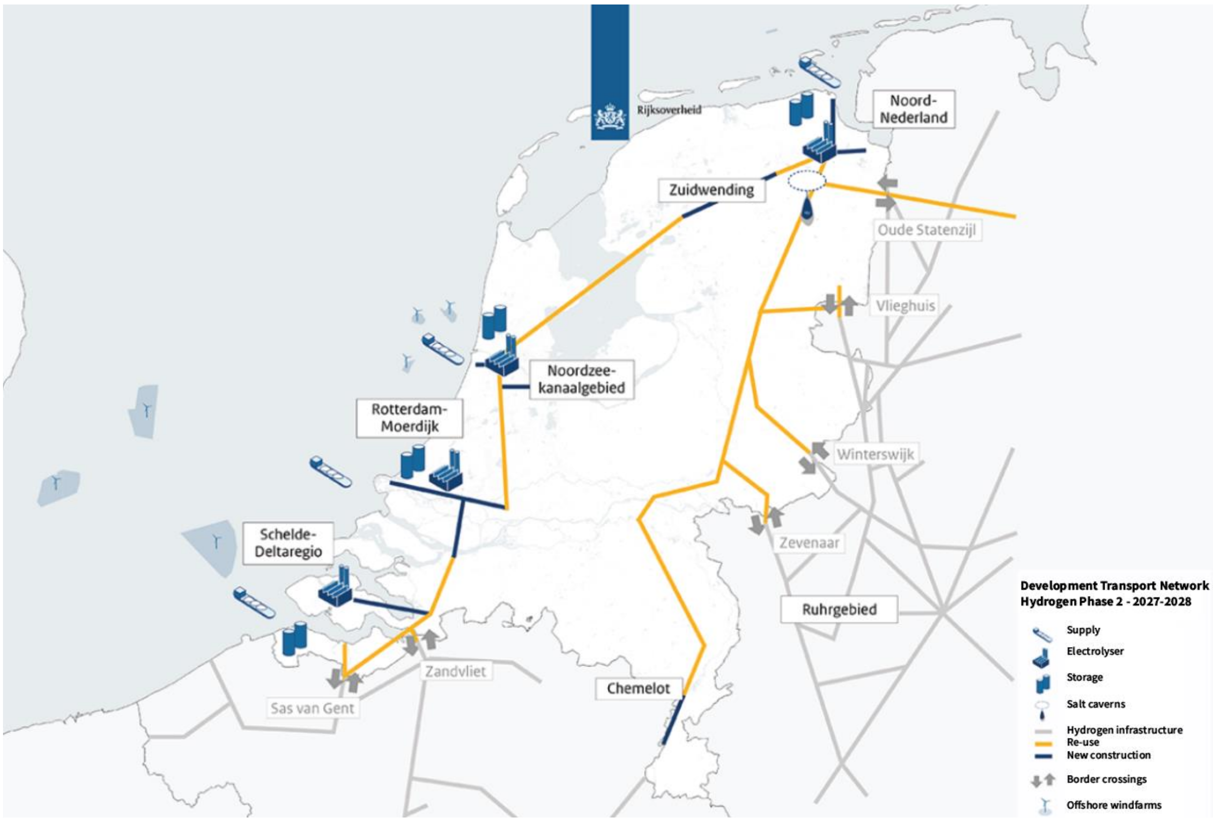

Figure 7: Phase 2 (Ministry of Economic Affairs and Climate, 2022)

Phase 3 – 2030
Between Zeeland and Chemelot, an additional tracing will be re-used (see figure 8). As a result, the network is closed, and many locations can deliver via two routes. This ensures supply security. Furthermore, transport capacity to Germany will be increased further (Ministry of Economic Affairs and Climate, 2022).

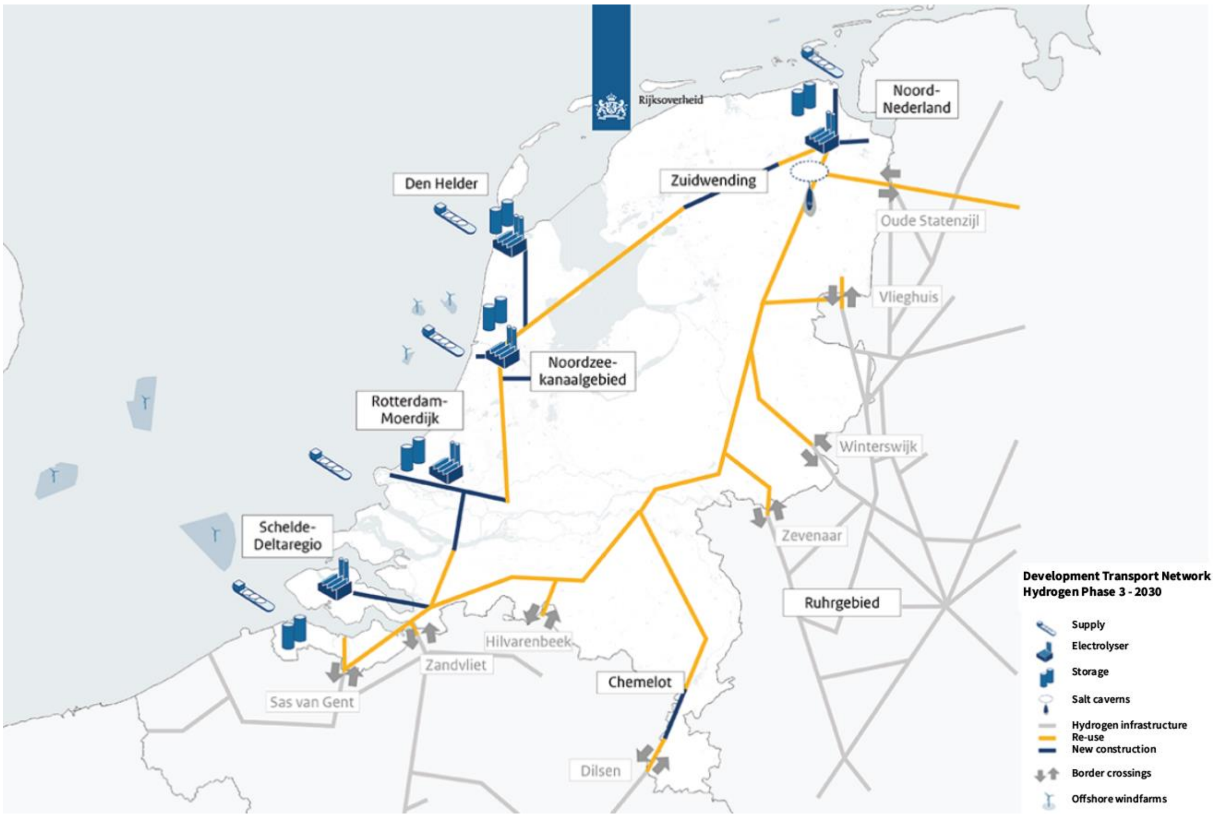

Figure 8: Phase 3 (Ministry of Economic Affairs and Climate, 2022)

After the third phase
The development of the transport network does not end with phase three. The demand for storage and distribution capacity will increase as the market develops. To increase the capacity of the transport network, the pressure can be increased to distribute more hydrogen through the network. Another possibility is that more gas pipelines will become available for hydrogen over time. To let the transport network contribute to the development of the Dutch hydrogen chain and make energy and fossil fuel usage more sustainable. HNS must develop the transport network at the right time and in the right place. However, it should be avoided that HNS charges exorbitant prices and profits are made at the expense of transport network users and hydrogen consumers (Ministry of Economic Affairs and Climate, 2022).

4.2 Hydrogen Valleys

Hydrogen Valley Platform was commissioned by the EU and developed by the Fuel Cells and Hydrogen Joint Undertaking (FCH JU)[1]. The Hydrogen Valley projects provide a first look into the global Hydrogen Valley Project landscape, its factors of success and the encountered barriers. FCH JU has been setting up Hydrogen Valleys in collaboration with European cities and regions. Hydrogen Valleys projects have emerged all over the world in recent years (see figure 9).

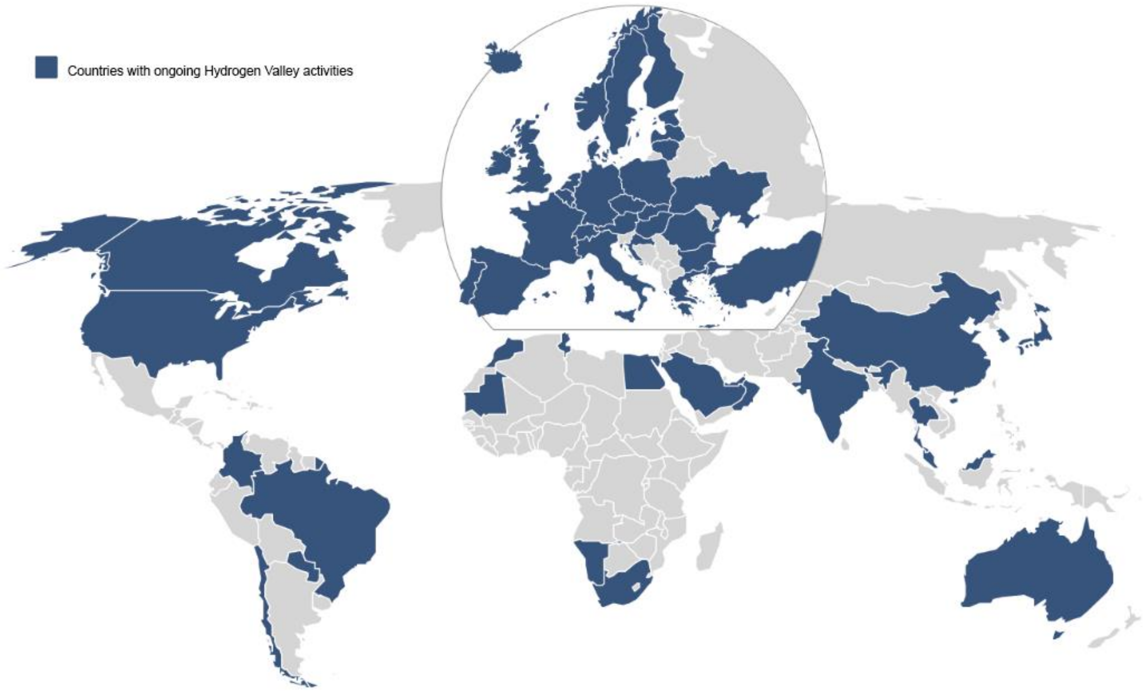

Figure 9: Ongoing Hydrogen Valleys activities (Weichenhain et al., 2021)

The concept aims to integrate hydrogen ecosystems at the local level for climate change mitigation and regional economic development. Hydrogen Valley covers a significant portion of the value chain, from hydrogen production, storage, and transportation to its final application in industries, mobility, and the built environment. Hydrogen Valleys will mature over the 2020s due to an increase in projects overall. The Netherlands also has ongoing Hydrogen Valley activities of which two will be discussed and analysed in this paragraph. Namely, HEAVENN (H_2 Energy Applications in Valley Environments for Northern Netherlands) and Europe's Hydrogen Hub: H_2 Proposition Zuid-Holland/Rotterdam (Weichenhain et al., 2021).

[1] Public-private partnership supporting research, technological development, and demonstration activities in fuel cell and hydrogen energy technologies in Europe.

4.2.1 HEAVENN

Figure 10: Location HEAVENN

HEAVENN is a large-scale demonstration project. By bringing together the central elements: production, distribution, storage and local end-use of sustainable hydrogen into a fully functioning Hydrogen Valley. European efforts concerning hydrogen have been individual efforts for the most part and this project aims at an integrated approach so that the hydrogen valley can serve as an example across Europe. The European Union has identified the northern Netherlands (Drenthe, Friesland, and Groningen) as the Hydrogen Valley (see figure 10). The concept is based on the deployment and integration of existing and planned project clusters across six locations in the northern Netherlands, namely Delfzijl, Eemshaven, Emmen, Hoogeveen, Groningen and Zuidwending. The aim is to utilise green hydrogen across the entire chain. The energy knowledge and infrastructure in this region combined with the energy-intensive industry present in this region form a perfect ecosystem (New Energy Coalition, 2022).

It is a six-year project that began in January 2020, with an EU subsidy of € 20 million and a public-private co-funding of € 70-80 million. The HEAVENN project involves cooperation with 31 public and private parties from six EU countries. The New Energy Coalition, the project's initiator, is among these public and private parties. Other key players include the province of Groningen, the province of Drenthe, FCH JU, Waterstof Hoogeveen, and Gasunie. The northern Netherlands is the first region to receive such a subsidy (New Energy Coalition, 2022).

A hydrogen-based economy starts with sustainable energy sources, generation, storage, and transport. This should eventually result in applications in industry and application in mobility and our built environment. First, offshore wind extraction and landing at Eemshaven Seaport, followed by production (electrolysers). Second, storage in the salt caverns of Zuidwending, followed by transport and distribution via the transport network/backbone. Third, offtake in energy-intensive industries in the industry clusters of Delfzijl and Emmen. Finally, there are housing projects in Hoogeveen. The development of mobility infrastructure, including hydrogen filling stations, completes the chain (New Energy Coalition, 2022). Figure 11 depicts the chain.

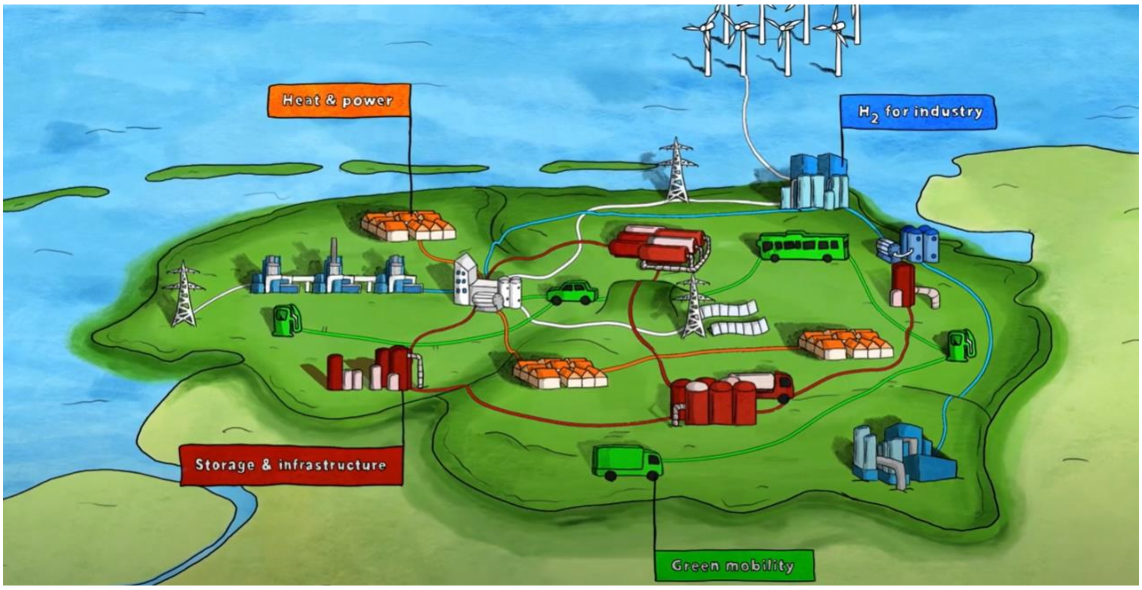

Figure 11: HEAVENN (New Energy Coalition, 2022)

The storage in salt caverns is particularly interesting to address for this specific demonstration project. Storage is necessary since renewable energy supply is not consistent. Hydrogen needs to be stored to have the security of supply. The northern Netherlands has the ideal underground for constructing the required salt caverns. A significant portion of this storage potential is located in Groningen near the Zuidwending near Veendam. Zuidwending is also close to a former natural gas transport network. This transport network will be developed into a sustainable hydrogen transport network in upcoming years as explained in paragraph 4.1.

Salt caverns are artificial underground salt formations which are created by the dissolution of rock salt by the injection of water during the solution mining process. This process takes three-four years before the salt cavern takes on the right size, about 500.000 m3 to 1.000.000 m3. When the salt cavern has finally reached the right shape and size it can be filled with gas (Gasunie, n.d.).

Figure 12 depicts the future energy storage system, which includes an electrolyser and the salt caverns being developed in Zuidwending. A visual comparison to the Eiffel Tower is made to illustrate the size. The connection to the transport network is shown on the bottom right. The hydrogen installation areas are already existent and were in use for natural gas pervious to this project. Therefore no major spatial adaptations are necessary above ground.

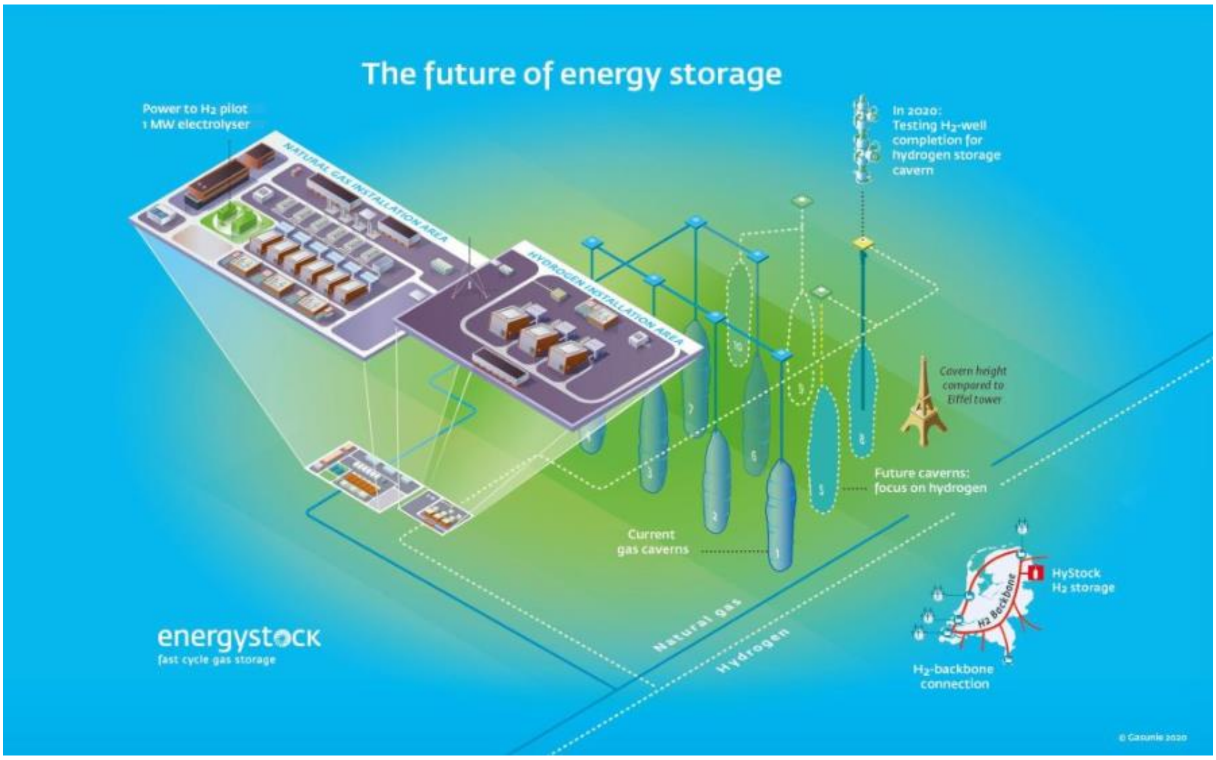

Figure 12: Energy storage (Gasunie, n.d.)

4.2.2 Europe’s Hydrogen Hub: H2 Proposition Zuid-Holland/Rotterdam

The Netherlands and the EU are preparing for massive renewable energy imports. northwestern Europe's energy consumption is so high that the region will be unable to produce enough renewable energy to meet demand. As a result, even after the energy transition, Europe will continue to import energy. As previously stated in chapter three, areas with a lot of sunshine or strong wind can produce green energy cheaply, which can then be used to produce green hydrogen. Green hydrogen can then be imported. Hydrogen can be transported in various ways. Some of the production countries would be too far away to transport hydrogen through a transport network as a gas. The transport network would be an interesting option for imports from Southern Europe and North Africa. However, imports from the Middle East must be transported in alternative ways, such as liquifying hydrogen and transporting it by ship. This is one of the drivers for the province of South-Holland and the city and the Port of Rotterdam to commit to becoming the hydrogen hub of Europe as seen in figures 13 and 14 (Port of Rotterdam, 2022).

Figure 13: Location Europe's Hydrogen Hub

Figure 14: Hydrogen hub of Europe (Port of Rotterdam, 2022).

The hydrogen system integrates hydrogen production, use, particularly in industry, imports, and transit flows across the Netherlands and Northwest Europe. The port and Gasunie are working on an initiative to have this transport network running through the port by 2023. This transport line will supply hydrogen to businesses. As mentioned in paragraph 4.1, this transport network will then be connected to the national infrastructure and foreign infrastructure. This will give Rotterdam a leading infrastructure in the field of hydrogen that will stimulate market development and maintain the important role of the port (Port of Rotterdam, 2021).

This project not only establishes the import and transit of energy flows but will also open the first conversion park for green hydrogen production by 2023 in close cooperation with Shell. This will be located on the Tweede Maasvlakte. Green hydrogen will be produced in the port and delivered to the industry, mobility, and the built environment via the transport network (Port of Rotterdam, 2021). Shell made renderings of what a conversion park would look like. Figure 15 depicts how much space such a conversion park would take up and what kind of impact it would have on one's surroundings.

Figure 15: Rendering electrolyser (Shell, 2021)

Data gathered from 30+ Hydrogen Valleys, which also included these two examples, gave a clear insight into key factors for successful project development and barriers to the development of Hydrogen Valleys.

Key factors for successful project development include:

- a convincing project concept that focuses on local resources (for example, abundant renewable energy sources);
- addresses local needs (for example, decarbonisation of local industrial production);
- as well as the development of a viable business case that demonstrates that off-takers of clean hydrogen are willing to pay;
- obtaining public support and funding for these projects is extremely crucial;
- during project development, stakeholder cooperation and effective partnering that ensures continuous commitment for all parties is essential;
- as is obtaining political backing from policymakers and public support (Weichenhain et al., 2021).

From this report, five barriers were concluded, however, these are not unconquerable. Most barriers concern the financing and the readiness of the project. However, this research also indicated some barriers regarding policymaking. These barriers will be further discussed below.

<u>Securing funding.</u> This is also the most prominent barrier. Creating awareness, initiating proactive dialogues and remaining flexible to potential adaptation of the project to match it to the public funding requirements proved to be successful in Hydrogen Valley projects (Weichenhain et al., 2021).

<u>Securing off-take commitments for clean hydrogen</u>. Talks with as many potential off-takers from various sectors as possible are among the best practices mentioned to reach the required off-take quantities (Weichenhain et al., 2021).

Structured development approach. To secure private funding Hydrogen Valley's relied on a development approach, early involvement of off-takers and equity partners that de-risk the project as well as early feedback from the lending community (Weichenhain et al., 2021).

Mitigating technological readiness and performance barriers. It is essential to remain flexible regarding the project's direction. This could lead to adding other applications to the project's portfolio (Weichenhain et al., 2021).

Permitting and regulating barriers. Policymaking barriers have an impact on Hydrogen Valleys both directly and indirectly. In a national hydrogen strategy that establishes the framework for Hydrogen Valley development and other hydrogen-related developments, policymakers should have a clear vision of the country's future hydrogen economy. Furthermore, a regulatory environment favourable to hydrogen development should be created, closing gaps in permitting procedures and acting as local matchmakers to enable the establishment of Hydrogen Valleys and other hydrogen developments (Weichenhain et al., 2021).

4.3 Waterstofwijk Hoogeveen

Waterstofwijk Hoogeveen refers to the new Nijstad-Oost neighbourhood within the municipality of Hoogeveen. The municipality is carrying out this demonstration project to demonstrate that implementing hydrogen in a neighbourhood is feasible. The municipality expands this project to the existing adjacent neighbourhood of Erflanden (see figure 17). This demonstrates that hydrogen application via the transport network is feasible in both new and existing neighbourhoods. This provides a solution for converting existing neighbourhoods to natural gas-free environments and incorporating natural gas-free housing into future plans and visions (Waterstof Hoogeveen, 2020).

This project aims to design a transition from natural gas to hydrogen for heating neighbourhoods in the Netherlands using the existing transport network (backbone). Waterstof Hoogeveen is a collaborator on the HEAVENN project, which was previously discussed in this chapter. Waterstof Hoogeveen contributes with their project known as Waterstofwijk Hoogeveen. Waterstof Hoogeveen realises housing projects as part of the larger concept of a Hydrogen Valley, making hydrogen applicable in the built environment (Waterstof Hoogeveen, 2020).

Figure 16: Hydrogen neighbourhoods (Waterstof Hoogeveen, 2020)

There are three methods for supplying hydrogen to homes within this pilot (see figure 17). Through external supply, local production, and the hydrogen backbone, which was discussed in paragraph 4.1.
External supply. Green hydrogen will be delivered via tubetrailers. Tubetrailers are connected to the storage. The pressure of the hydrogen is reduced from 300 bar to 80 bar and stored. Storage is necessary to maintain a buffer between supply and demand. An external supply is ideal for neighbourhoods that are being set up to transition and have a relatively low demand. The hydrogen is then transported to the gas delivery station (GOS). GOS reduces the pressure to 4 bar and odorises the hydrogen. Green hydrogen is then transported to the distribution network. The distribution network consists of pipelines that transport hydrogen to individual homes. The pressure gets reduced to 100 millibars in the distribution network. The hydrogen central heating boiler in the house is supplied with hydrogen from the hydrogen distribution network via indoor pipes (Waterstof Hoogeveen, 2020).

Local production. Green energy generated by solar parks or wind farms is connected to an electrolyser, which produces green hydrogen. Hydrogen is transported to a compressor, which is required to achieve the proper pressure for importation into the transport network (Waterstof Hoogeveen, 2020).

Hydrogen backbone. The hydrogen backbone is used to supply hydrogen. The GOS will be connected to the backbone and will provide hydrogen to the hydrogen distribution network. This ensures the security of supply (Waterstof Hoogeveen, 2020).

Figure 17 depicts the three types of green hydrogen supply methods. For every method, it shows where they enter the supply chain.

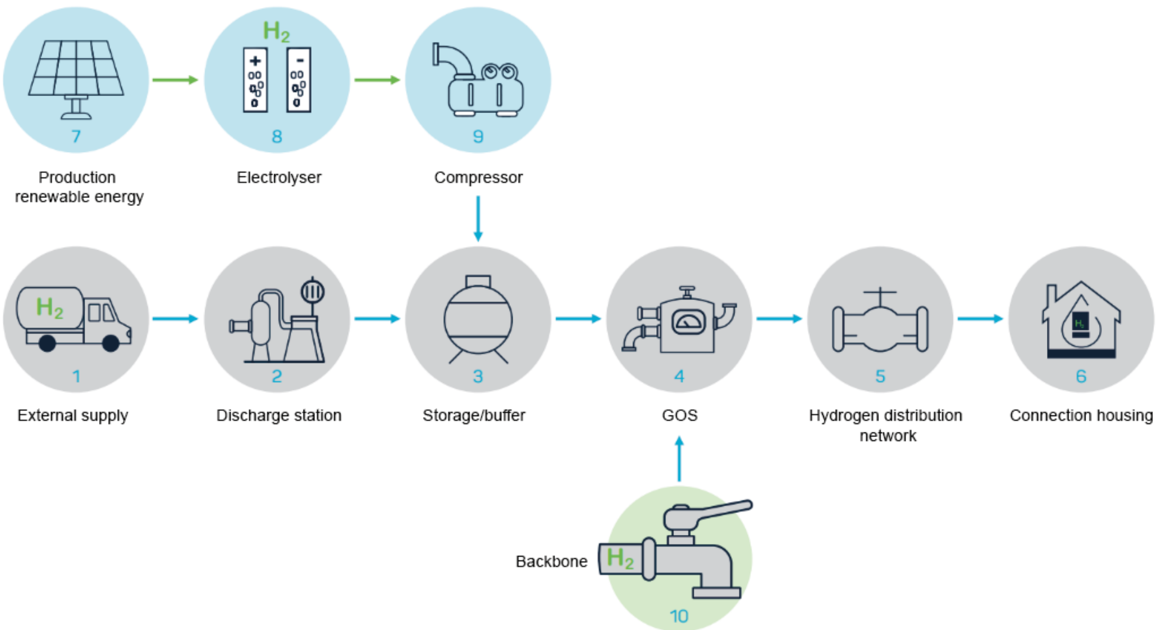

Figure 17: Hydrogen supply (Waterstof Hoogeveen, 2020)

4.3.1 Barriers

Waterstof Hoogeveen's research report provides a clear insight into the barriers encountered during this demonstration project. In the built environment, hydrogen is still unknown. As a result, much of the legislation pertains to natural gas, and there is currently no legislation pertaining to hydrogen. As a result, there is a legislative gap in the areas. That is, as long as there is no hydrogen legislation similar to or as part of the Gas Act or Heat Act. Agreements between different parties in the hydrogen chain must be contractually agreed upon (Waterstof Hoogeveen, 2020).

The security of supply is critical when using hydrogen as a heating element in the built environment. As a result, multiple methods of supplying hydrogen to a neighbourhood must be present. If one option fails, there is a backup that can still supply homes while also replenishing the buffer. As a result, Waterstofwijk Hoogeveen established three possible supply routes, ensuring supply security (Waterstof Hoogeveen, 2020).

Some minor adaptations are necessary for the house to make it safe for hydrogen. A gas boiler, gas meter, gas heater, and gas stove would need to be replaced by hydrogen-safe appliances. For future plans and visions, it is crucial to decide who is going to subsidise these adaptations (Waterstof Hoogeveen, 2020).

4.4 Conclusion

In conclusion, the pilots and demonstration projects presented in this chapter were the development of the Netherlands' transport network, also known as the backbone, the Netherlands' Hydrogen Valley: HEAVENN, and Europe's Hydrogen Hub and Waterstofwijk Hoogeveen. These pilot and demonstration projects are all linked to one another and thus highly dependent on one another. A few barriers have been discovered during the course of these projects that must be addressed. These barriers included securing supply, funding of hydrogen-safe appliances, and creating a regulatory environment to close the legislative gap.

5. Conclusion & recommendations

During the writing of this report, insights were gained. In this chapter, the conclusion and findings of this research report will be presented. Upon these findings, a recommendation is made regarding the implementation of green hydrogen into the built environment.

5.1 Conclusion

(Dis)advantages of green hydrogen utilisation can be concluded after researching green hydrogen in general. Advantages are:

- making polluting sectors more sustainable;
- green hydrogen can be stored sustainably;
- hydrogen implementation requires minor adaptations;
- green hydrogen produces a sustainable by-product.

Disadvantages are:

- a lot of energy is lost during the production of green hydrogen;
- there is currently low availability of green hydrogen;
- green hydrogen is expensive;
- people are distrustful of hydrogen utilisation.

Developing demand, supply, storage, and infrastructure comes with vast dependencies between them. Therefore, there must be input from the international, national, regional, and municipal levels. This results in a large network of persons and organisations concerned with hydrogen. First, on an international level, the EU is needed to bring new solutions to the market and provide a large-scale infrastructure network. The Port of Rotterdam is needed to create a hub function for international energy flows. But international energy flows are also needed for the Port of Rotterdam to maintain that hub function. Therefore import is also important. Regions such as the Middle East and North Africa need to build an export sector.
Second, on a national level, the central government will have to establish a framework as well as define and enable powers and obligations. This policy framework should be capable of facilitating ambitious plans. This is critical for businesses involved in green hydrogen to start their projects.
Third, on a regional level, provinces with knowledge of gas need to develop a new (economic) perspective. Regional authorities and organisations, such as regional network operators, are essential in developing and facilitating local infrastructure.
Finally, on a municipal level, it is the responsibility of municipalities to discuss the transition with stakeholders such as residents, agricultural holdings, and property owners, as well as conduct the necessary research to make an informed decision. Eventually, municipalities will be in charge of issuing permits and establishing installations for decentralised hydrogen production and storage. Housing cooperatives will have to be involved due to hydrogen-proofing homes with hydrogen-proof appliances.

Within the Netherlands, developments are taking place to start shaping the energy transition. Some of these developments were analysed and this analysis led to insights. The first development was the development of the transport network for green hydrogen (backbone). What can be concluded from this project is that this is the most crucial development currently. The other projects that were analysed in this report are all dependent on this transport network. Following, two Hydrogen Valleys were presented. These gave an insight into what barriers are encountered during the development of such a project. The barriers are:

- securing funding;
- securing off-take commitments for clean hydrogen;
- having a structured development approach, which is necessary to secure funding;
- a missing regulatory environment, resulting in permitting and regulating barriers.

Hydrogen Valleys also gave insight into key factors to overcome these barriers. These are:
- a concept focusing on local resources;
- addressing local needs;
- developing a viable business case, showing that off-takers are willing to pay;
- stakeholder cooperation;
- obtaining political backing from policymakers and the public.

Last, a project on neighbourhood level is presented in this report. Waterstofwijk Hoogeveen revealed multiple ways of supplying green hydrogen. Green hydrogen can be supplied through external supply, local production, and the hydrogen backbone. These methods can be applied in both new and existing neighbourhoods. This project revealed barriers such as:
- a legislative gap in the areas of market regulation, supply security, and consumer protection in the supply of hydrogen;
- security of supply;
- minor adaptations that are necessary for hydrogen-proofing houses and the subsidising of these adaptations

After gaining insights into green hydrogen through analysing the (dis)advantages and different projects on different levels, the final barriers can be concluded. These are:
- Securing funding, including subsidising adaptations for hydrogen-proofing houses.
- A legislative gap that makes it difficult to secure off-take commitments and regulate the market in general.
- Security of supply.
- Missing a policy framework.
- Making hydrogen compatible with other fossil fuels. Because of its current low availability and high cost.

At the spatial planning level, these barriers reveal encounters. These projects exposed minor design challenges at the neighbourhood level.

5.3 Recommendations

From the literature and case studies presented in this report, a recommendation can be made regarding the implementation of green hydrogen into the built environment. During this research, barriers and general points of attention were discovered. This paragraph will describe the barriers and points of attention and what is necessary to overcome these.

Two general points that are crucial for the implementation of hydrogen are:
<u>Green hydrogen must always be used.</u> Green hydrogen must be used in this energy transition to achieve climate neutrality by 2050, and the source of the hydrogen must always be considered. Green hydrogen production must be scaled up if it is to be implemented in all sectors. There are currently insufficient solar parks, wind farms, and electrolysers to supply sufficient green hydrogen. More green hydrogen can be produced and more sectors can transition to green hydrogen by scaling up. Green hydrogen is currently more expensive due to insufficient supply. By increasing the scale of green hydrogen production, costs will be reduced and it will be compatible with other fossil fuels. Upscaling also promotes supply security, which is critical when implementing green hydrogen in the built environment. Both private and public investors will need to make investments.

<u>Implementation in the industry first.</u> Green hydrogen should be implemented and utilised in the industry first before it can be implemented in different sectors. Grey hydrogen is already widely used in the Dutch industry. This results in a lot of knowledge about handling hydrogen safely and responsibly. In the industry, there is already an infrastructure and economic foundation in

place for hydrogen. Replacing this with green hydrogen can serve as an example and foundation for the implementation in different sectors, such as the built environment.

The barriers identified in the conclusion will be addressed with recommendations to help overcome these challenges.

Table 3: Recommendations to address barriers

Barriers	Recommendations to address the barriers
Green hydrogen should be made compatible with other fossil fuels.	Upscaling is required to reduce costs and supply sufficient hydrogen. This will also increase the security of supply.
There is a legislative gap that needs to be reduced.	Hydrogen legislation should be enacted in a manner similar to or as part of the Gas Act or Heat Act. The Dutch government should create a regulatory environment. Meanwhile, agreements between various parties must be contractually agreed upon to secure off-take commitments.
Policy barriers should be reduced.	A framework and national policy should be developed to support ambitious plans while clearing policy barriers.
Funding needs to be secured.	Both private and public investors must make investments. Funding can be secured by raising awareness, initiating proactive dialogues, and remaining flexible to potential project adaptations to meet public funding requirements.
A subsidy for adaptations in the house should be provided.	A subsidy is required to complete the transition to green hydrogen in the built environment. The housing cooperative will most likely provide this subsidy.

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