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Doubling Down on Hydrogen - Are the Dutch Leading the Way?

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Abstract

This research engages in an intricate exploration of the catalysts and impediments operative within the Dutch hydrogen supply chain, instrumental to the nations decarbonisation pursuits. Situating the Dutch context within the global hydrogen landscape and EU regulations, the study gives a granular dissection of the upstream, midstream and downstream of the supply chain. The Dutch prospects of developing into an essential hydrogen hub, playing on inherent strengths as infrastructure and expertise, resources, and strategic alliances, are evaluated. Simultaneously, the study assesses the major pitfalls for the Netherlands, which include supply constraints pertaining to imports, scarcity of sufficient hydrogen molecules for effective decarbonisation of industrial clusters, and cost-related constraints pertaining to the hydrogen ramp-up. The study highlights the temporal indispensability for blue hydrogen, while stressing the need for policy regulations to prevent carbon and infrastructural lock-ins in a brief window of opportunity for climate mitigation.

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I would like to thank all those who have taken significant amounts of their time to be interviewed and wanted to have elaborate discussion on hydrogen with me. This has made the research process very rich. I hope to be able to have many more such conversations with you in the future.

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BAU (Business As Usual)

CCS (Carbon Capture and Storage)

DCI (Dutch Chemical Industry)

DER (Deep Emissions Reduction)

EHB (European Hydrogen Bank)

ETS (Emission Trading System)

EU (European Union)

GHG (Green House Gasses)

IPCEI (Important Projects Of Common European Interest)

IRA (Inflation Reduction Act)

LOHC (Liquid Organic Hydrogen Carrier)

MEAC (Ministry of Economic Affairs and Climate)

MFA (Ministry of Foreign Affairs)

MIWM (Ministry of Infrastructure and Water management)

MLP (Multi-Level Perspective)

MoU (Memorandum of Understanding)

Mtpa (Million Tonnes Per Annum)

Mt (Million Tonnes)

NGO (Non-Governmental Organisation)

PJ (Peta Joule)

RED (Renewable Energy Directive)

RFNBO (Renewable Fuel of Non-Biological Origin)

RES (Renewable Energy Sources)

SMR (Steam Methane Reforming)

Introduction

Hydrogen In Energy Systems: An Examination of the Dutch Supply Chain

Hydrogen, in its various roles and applications in energy systems, is now at the forefront of debates. The heightened interest from policy makers, industries, governments, NGO’s, research institutes, and companies emanates from the conviction that the molecule holds substantial promise for tackling climate change. The focus has mainly intensified with regard to renewable and low-carbon hydrogen, produced through the process of electrolysis and Steam Methane Reforming (SMR) with Carbon Capture and Storage (CCS).[1] These two production processes of hydrogen, referred to as green and blue hydrogen respectively, have found their way into the national strategies of almost every country in the world today.

The EU hydrogen ambitions include a swift fossil-free hydrogen market ramp-up, with 10 million tons (Mt) of diversified hydrogen imports, 10 Mt of domestic production, and the establishing of a European hydrogen backbone by 2030. It is in this context of these goals that the present study unveils the intricate barriers and accelerators for the Dutch hydrogen and decarbonisation ambitions. In this exploration, we inquire into the essence of the progress that has been made within the hydrogen field in the recent years on both the EU and the national level, seeking to dissect the hydrogen catalysts and impediments towards a sustainable and carbon-neutral future. It is in this light that the following research question is proposed:

> *What are the factors that accelerate or inhibit the hydrogen supply chain necessary for the Dutch Hydrogen and Decarbonisation goals?*

The present research aims to develop a deep understanding of the accelerators and inhibitors that are of importance to the development of the Dutch hydrogen supply-chain. Through the identification and analyses of such accelerators and inhibitors it will become possible for decision makers, companies, and stakeholders to develop strategies that can both address the shortcomings of the current strategy, as well as built upon current strengths.

[1] Veenstra, Arjen, and Machiel Mulder. "Economics of hydrogen production: assessment of investment in electrolysers under various circumstances." (February 2023) p.4.

More specifically, the study comprehensively investigates the different components of the Dutch hydrogen supply chain, encompassing upstream activities such as production and import, midstream processes including infrastructure and storage, as well as downstream utilisation in industrial applications. In doing so, the thesis explores the potential of the hydrogen molecule to support the decarbonisation objectives of the Netherlands while simultaneously evaluating its potential in preserving the country's position as a trading hub that supports its key industries. The Netherlands presents a particularly compelling case study, given its substantial demand for green energy driven by sizeable industrial clusters and its close proximity to the German Ruhr area. In the last 70 years the Netherlands has also been the largest natural gas hub of the EU and therefore a specialist in handling molecules. This combination of high energy demand, prominent industrial clusters, and ambitious decarbonisation targets make it an excellent case study for the role of hydrogen within energy systems.

The paper employs the terms "green hydrogen" or "renewable hydrogen", "blue hydrogen" or "low-carbon hydrogen" and "grey hydrogen" or "fossil-based hydrogen". To provide clear understanding, the meanings of the terms are elucidated in the Table 1 below. When the thesis refers to "hydrogen", green or renewable hydrogen is presumed.

Table 1 — Hydrogen Colour Definitions

<table>
<tr><th>Hydrogen by new definitions</th><th colspan="2">Hydrogen by colour</th></tr>
<tr><td>Renewable hydrogen (sometimes referred to as clean hydrogen)</td><td>Green hydrogen (renewable electricity through electrolysis)</td><td rowspan="3">Electricity from grid (electrolysis)</td></tr>
<tr><td>Low-carbon hydrogen</td><td>Blue hydrogen (natural gas with CCS)</td></tr>
<tr><td>Fossil-based hydrogen (without CCS)</td><td>Grey hydrogen (natural gas), brown hydrogen (brown coal), black (black coal)</td></tr>
</table>

Source: EPRS Erbach, G. and Svensson S. EU rules for renewable hydrogen (April 2023) p.3.

Methodology

To start, in Chapter 1, the paper will sketch-out the current state of play within the hydrogen scene thus far, highlighting the recent developments from a global, EU, and national perspective. Then in Chapter 2, the specific accelerators that accentuate the Dutch hydrogen position are discussed, answering the question to what extent the Netherlands can be seen as an exemplary case-study for the European hydrogen ambitions. Chapter 2 also maps the stakeholders present in the Dutch hydrogen landscape. These include stakeholders from all relevant factions of the supply-chain. Chapter 3 investigates the bottle necks for the EU and Dutch hydrogen ambitions. Finally, in the conclusion, the key-findings are presented that demonstrate the strengths and limitations of the Dutch hydrogen supply-chain.

The literature review encompasses a thorough analysis of the relevant academic literature, scientific articles, books, and other publicised works that have a direct relevance for this paper. The literature study allows to identify gaps in the knowledge base which has helped the paper to identify where further research is needed for answering the research question.

The paper uses 17 semi-structured interviews with a diverse range of senior stakeholders who are involved in the Dutch hydrogen supply chain. These stakeholders were carefully selected to present a broad spectrum of perspectives, encompassing government and policy advisors, academics and research professionals, port authorities and infrastructure representatives, and consultants in the hydrogen sector. The questions asked to the interviewees during the interview (which took place via Teams) focused on answering the main research question for this paper and follow-up questions are asked for clarification. In this way the researcher is able to discover new insights pertaining to the research field. The open nature of the questions asked facilitate depth and allows for the emergence of new concepts.[2] All interviews were conducted in the same way, but alterations in the order of the questions were made to better suit the flow of the conversation. For ethical reasons and to respect the privacy of the respondents, it was chosen to anonymise the answers. Table 2 gives an overview of the hydrogen experts interviewed.

[2] Doody, Owen, and Maria Noonan. "Preparing and conducting interviews to collect data." (2013). p.3.

Table 2 – Overview of Conducted Expert Interviews

Interview Number	*Category*	*Role*
1	Port Authority and Infrastructure	C-Level
2	Energy company	Hydrogen Project Manager
3	Infrastructure	Hydrogen Project Manager
4	Green Finance Institution	Research
5	Government and Policy Advisors	Policy Advisor to Dutch Government
6	Port Authority and Infrastructure	C-Level
7	Research	Carbon Lock-in Specialist
8	Research	Hydrogen Technology Specialist
9	Consultancy	Hydrogen Consultant
10	International Advisory Association	Policy Advisor
11	Energy and Hydrogen Specialists	Energy Specialist in Hydrogen Trading
12	Research	Hydrogen Research Specialist
13	Energy and Hydrogen Specialists	Hydrogen Technology Specialist
14	Energy and Hydrogen Specialists	Hydrogen Chemistry Specialist
15	Government and Policy Advisors	Hydrogen Valley Expert
16	Government and Policy Advisors	Policy Advisor to Dutch Government
17	Port Authority and Infrastructure	C-Level

Theoretical Framework: Multi-Level Perspective

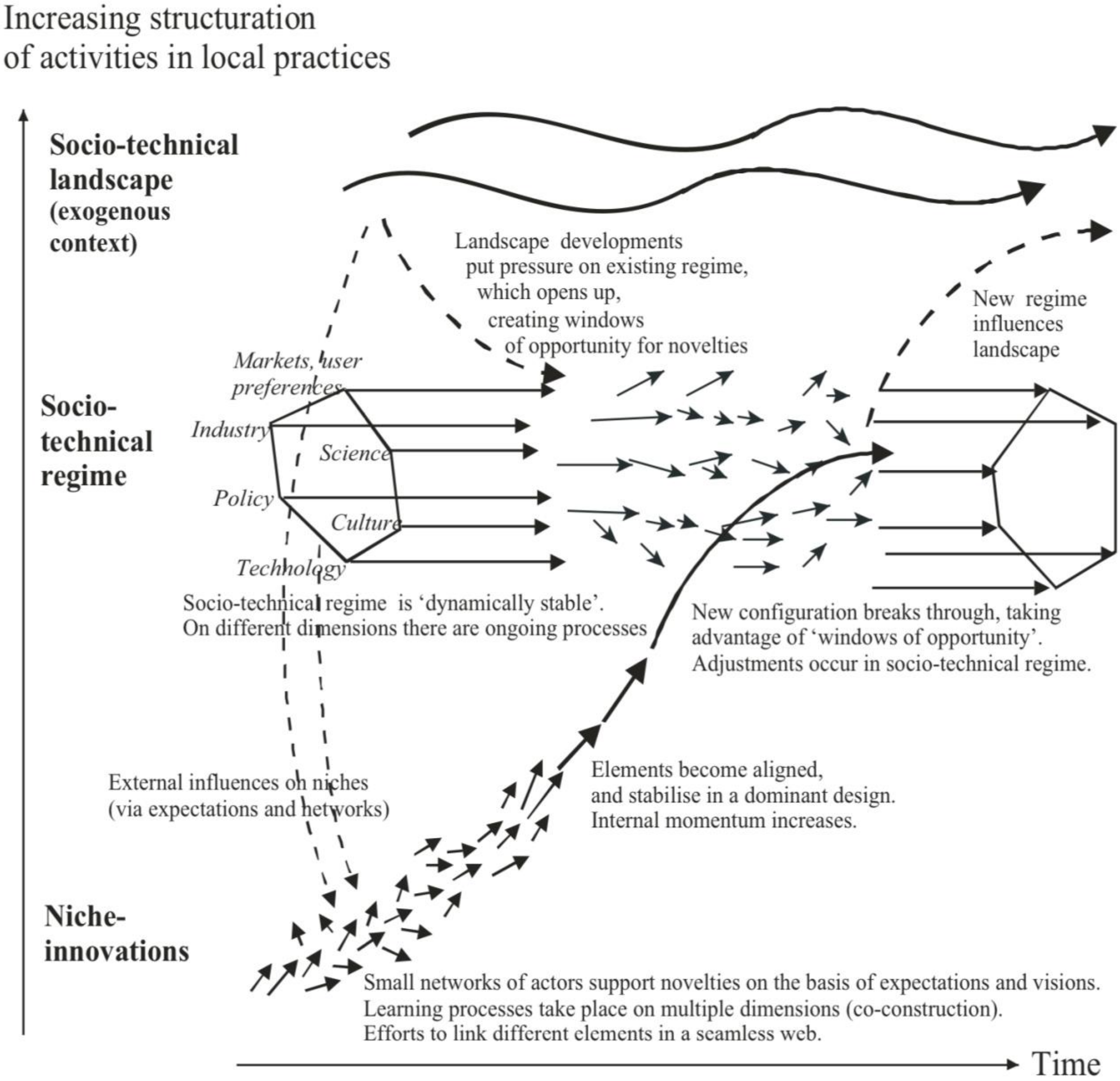
This paper uses Geels's Multi-Level Perspective (MLP). The MLP is a theoretical framework used to understand and elucidate the dynamics of societal change in the energy transition process. The MLP, developed by Geels, aims to explain the interaction among technology, institutions, and markets as the driving power behind transformative changes in different systems.[3]

The MLP consists of three societal layers, namely, landscape, the regime, and the niche. The landscape represents the context in which a system or sector is operating and includes macro-economic, ecological, and social-cultural factors. Regimes are the established order, institutions, norms, rules, and modes or routines that are dominant within (energy) systems. Niches are the experimental spaces in which new technologies, practises, and approaches are developed.

In the context of this paper, the MLP provides a valuable theoretical framework in which the data from the semi-structured interviews and literature analysis are placed. It allows for the in-depth analysis of the dynamics within the Dutch hydrogen supply chain. Specifically, hydrogen considered as a niche technology, could make a 'breakthrough' as societies move towards climate-neutral technologies. The landscape level in the MLP is outside of the control of the socio-technical regime (the established order). It is through this pressure that a "window of opportunity" is created that allows a new technology such as hydrogen to breakthrough. As the use of hydrogen in the European and Dutch context would require significant changes to current industrial models and infrastructural arrangements it is considered a transition. Figure 1 shows the MLP on (energy) transitions.

[3] Geels, Frank W. "The multi-level perspective on sustainability transitions: Responses to seven criticisms." Environmental innovation and societal transitions 1.1 (2011)

Figure 1 — Multi-level Perspective on Transitions

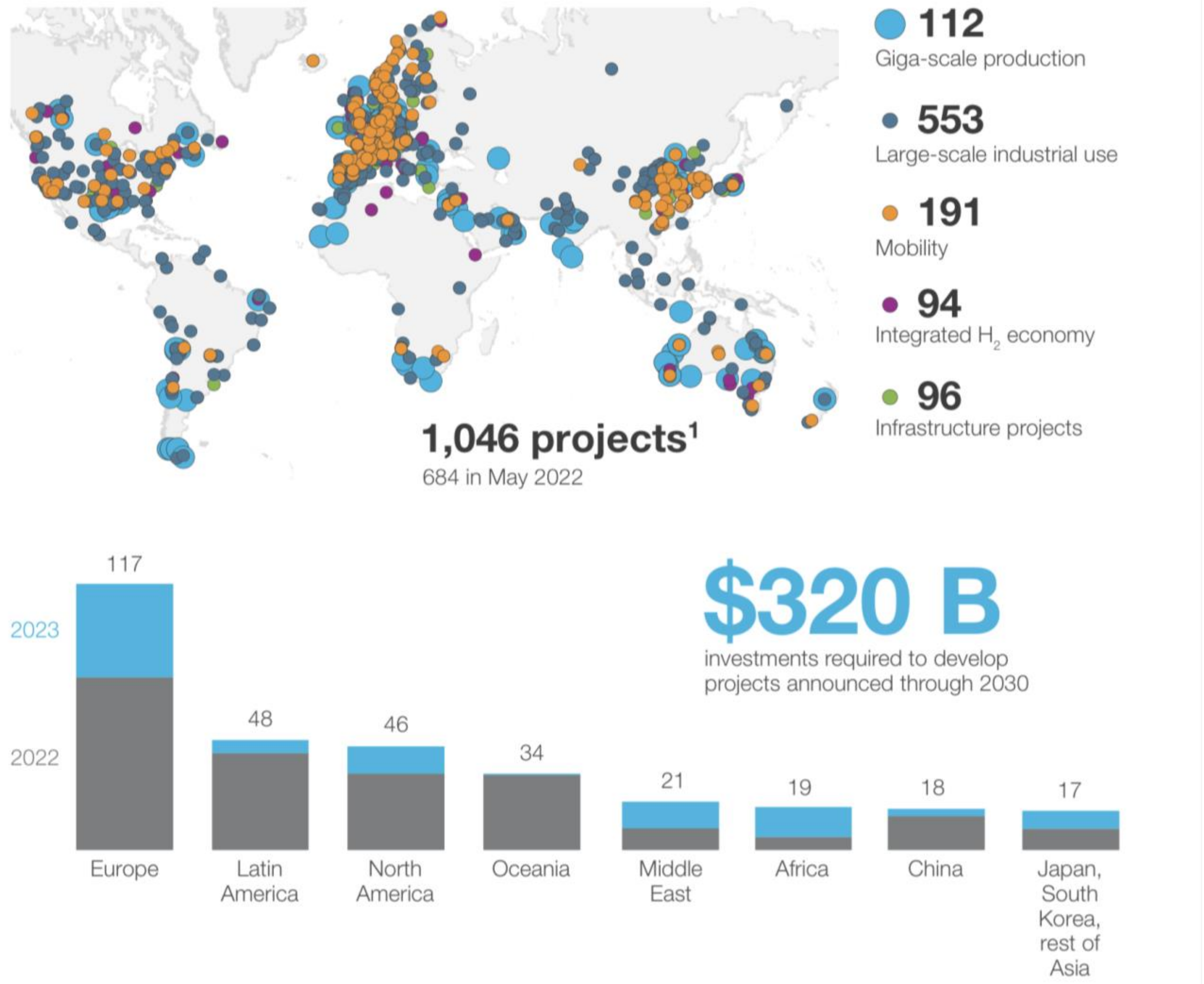


Source: Geels, Frank W. (2011) p.28.

Chapter 1: Are the Dutch Doubling Down on Hydrogen?

In this chapter, we explore the evolving hydrogen landscape, beginning with a global perspective before narrowing our focus towards the developments on the EU level, and ultimately, zeroing in on the Netherlands. Our research highlights the context and the recent developments within the global hydrogen scene, aiming at deriving insights in the global use of the molecule. We then turn our attention to the initiatives and policies of the EU, which play a pivotal role in shaping the development of hydrogen in member states. Lastly, we delve into one such member state and highlight how specific hydrogen strategies have been employed in the Netherlands, as the country navigates the path towards a sustainable hydrogen economy. Figure 2 shows the global developments in hydrogen investments and projects.

Figure 2 — Global Hydrogen Investments and Projects



Source: Hydrogen Council. Hydrogen Insights (May 2023) p.5.

The Global Hydrogen Dynamic

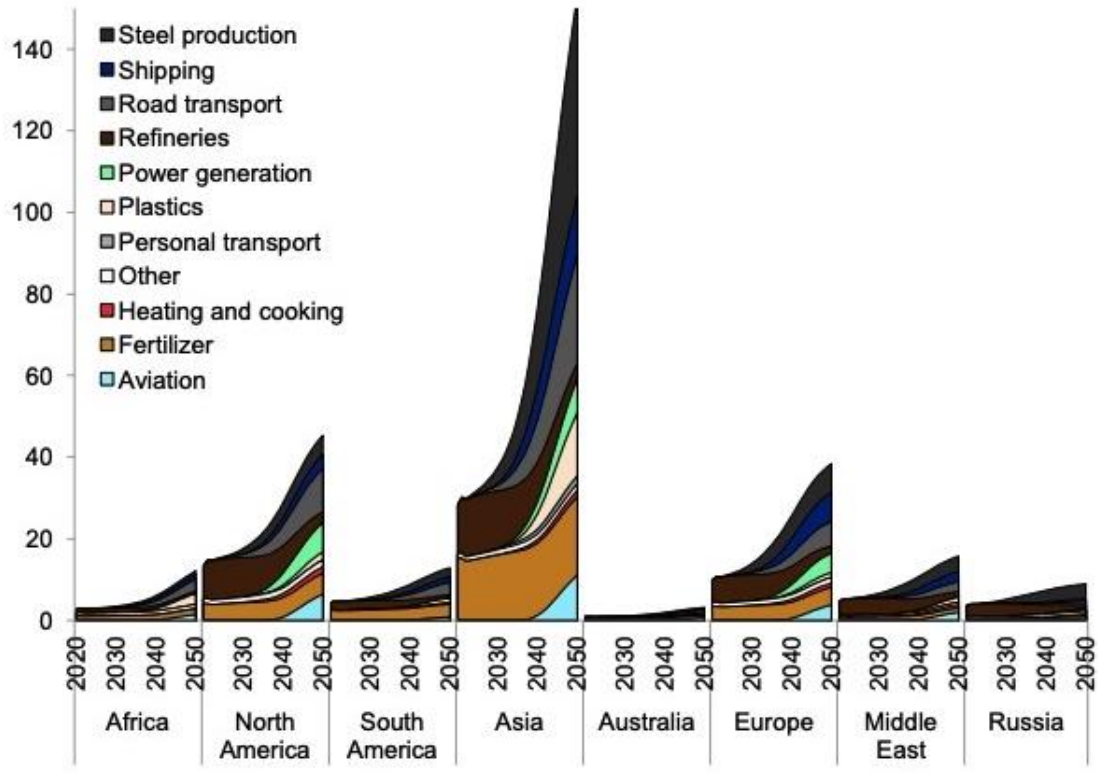
The global hydrogen landscape has been marked by significant changes over the last years. The number of countries that have released a hydrogen strategy have shot up. Globally, as of 23rd of May 2023, 45 countries have released or are working on a hydrogen strategy.[4] Additionally, the number of hydrogen projects have seen a raise as well, with 242 new projects launched globally in 2022. This would add around 22.5 Mt of hydrogen to the project pipeline. The expectation is that by 2050, 83% of the total hydrogen market share will be covered by green hydrogen, whereas blue hydrogen will only have 17% of the total market share.[5] By 2050, the sales of hydrogen as a commodity and the trade in the related equipment could have a worth of around $2.5 trillion per year and could generate 30 million jobs. Furthermore Bloomberg New Energy Finance estimates that hydrogen could meet 24% of final energy demand worldwide.[6]

The ambitions and interest for the hydrogen molecule are growing, and many scholars point to use case for hydrogen to promote efforts for an increased climate action, in line with the Paris Agreement and in line with the Sustainable Development Goals (SDGs) of the United Nations, mainly the SDG 13, 'climate action'.[7] Hydrogen is increasingly seen as a contributor to these SDG's, due to its ability to act as a tool for decarbonisation that allows for the reduction in emissions and greenhouse gasses (GHG).[8] The development in the field has also been boosted by the fossil-fuel price shocks after the war in Ukraine and the decreasing cost of renewable energies. But, as Notteboom points out, the take-off demand period for green hydrogen will most likely spike only by the mid-2030s.[9] This expected growth in demand is related to technological development, the rollout of infrastructure, and cost reduction, through which green hydrogen will become more efficient and more cost competitive.

[4] https://www.weforum.org/agenda/2022/08/green-hydrogen-climate-change-energy/
[5] Rystad Energy: The condensed version - Energy Transition Report Hydrogen Market Update-The Hydrogen Economy in 2023 – (January 2023) p.4-5.
[6] Van de Graaf, Thijs. "The next prize: geopolitical stakes in the clean hydrogen race." (2020) p.32.
[7] Genovese, Matteo, et al. "Power-to-hydrogen and hydrogen-to-X energy systems for the industry of the future in Europe." (2023) p.2.
[8] Mneimneh, Farah, et al. "Roadmap to Achieving Sustainable Development via Green Hydrogen." (2023)
[9] Notteboom, Theo, and Hercules Haralambides. "Seaports as green hydrogen hubs: advances, opportunities and challenges in Europe." (2023): p.2.

Demand, (as seen in Figure 3), for the molecule will be strongest in Asia, due to the heavy industries (that use hydrogen for steel and cement making) present in countries like China and India, which contribute hugely to the glut for the molecule.[10] The second and third place, according to Rystad Energy, will be taken by the EU and North America respectively. Yet, the EU will be a different market than the North American one. For the EU imports are crucial, whereas the United States (US) can domestically produce a significant part of its hydrogen. The countries that enjoy significant renewable potential, Australia, Africa, South America, the Maghreb and the Middle East, will mainly cater towards the export of the molecule. With regard to the off-take of the molecule, hydrogen will be increasingly used to decarbonise assets of companies including those of Shell and BP, who could use it to decarbonise their refineries.[11]

Figure 3 — Hydrogen Demand at Various Continents (million tonnes)



Source: Rystad Energy. Energy Hydrogen Cube (2023) p.8.

[10] Yang, Xi, et al. "Breaking the hard-to-abate bottleneck in China's path to carbon neutrality with clean hydrogen." Nature Energy (2022)
[11]Rystad Energy, The condensed version - Energy Transition Report Hydrogen Market Update The Hydrogen Economy in 2023 – (January 2023) p.8-9.

In parallel to these dynamics, tectonic shifts are taking place within the hydrogen landscape caused by recent policy changes. For instance, the US Inflation Reduction Act (IRA) shook up global supply-chains and the coming of the IRA has led to shockwaves within the European hydrogen scene. The Act, which includes a simple and efficient hydrogen legislation, is, in the words of Jorgo Chatzimarkakis, CEO of Hydrogen Europe (a hydrogen industry lobby), "a clear statement of intent from the Biden administration that the largest economy in the world wants in on clean hydrogen."[12]

For the EU, the passing of the IRA has implications, as the US is now subsidising green hydrogen production with a $3 hydrogen tax credit, making the business case for hydrogen stronger than in the EU. The EU is mainly prescribing targets and providing funding and grants and does not subsidise hydrogen production or hydrogen use.[13] It is essential to consider the implications of this act. Some scholars like Kleiman, are critical whether such WTO inconsistent blows to the international trading system would not trigger protectionist responses in other countries, including the EU, which would render "international trade in green technology more fragmented and less effective in supporting the net-zero transition."[14] But, the IRA, with its 'carrots and no sticks' approach, could also be considered an important driver for the EU hydrogen landscape as the EU was forced to come up with a response after various stakeholders indicated their intent to move their industries across the Atlantic in search of more favourable hydrogen policy.

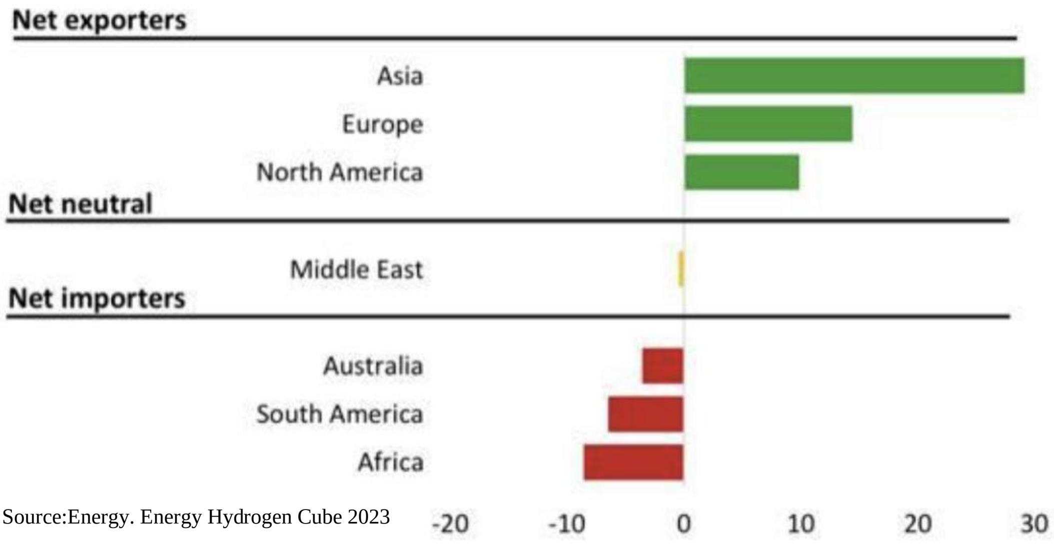
The EU Hydrogen Landscape

The Fit-for-55 (reducing GHG emissions by 55% by 2030) package, the REPowerEU plan, the European Hydrogen Backbone, and the European Hydrogen Bank (EHB) are EU initiatives that drive the green agenda of the EU and stimulate the development of the hydrogen supply chain across member states. Under these policies the EU Hydrogen landscape is rapidly evolving, and hydrogen is now officially part of all eight of the European Commission's net zero emissions scenarios for 2050.[15] The Fit-for-55 package of July 2021, has developed a number of proposals that translate the EU hydrogen strategy into a more concrete European policy framework and the NextGenerationEU has become available for

[12] Hydrogen Europe Quarterly (Q1) – Building A Global Hydrogen Market (2023)– p.6.
[13] Appendix A – Interview 10 "Policy advisor for an international advisory organisation"
[14] Kleimann, David, et al. "How Europe should answer the US Inflation Reduction Act." (2023) p.2.
[15] van Renssen, Sonja. "The hydrogen solution?" (2020): p799

countries to invest in hydrogen projects that are deemed important to the whole value-chain.[16] The Fit-for-55 package includes the revised RED II, which sets a target of a 40% share of renewable energy sources (RES) in total final energy consumption by 2030. As part of the The REPowerEU plan, launched in May 2022, which aims at reducing dependence on imported Russian gas and allowing for a new energy infrastructure that will enable the EU to decarbonise, this target was increased to 45% share by 2030. In March 2023, it was provisionally agreed to set the target at a 42.5% share by 2030.[17] Furthermore, the EU has committed to scaling up 100 hydrogen valleys, which are necessary to reduce reliance on fossil fuels. A hydrogen valley expert interviewed on this argues that such projects are a EU "success" story, the financing of which will be distributed through subsidies and guaranty mechanisms such as through the Important Projects of Common European Interest (IPCEI's) and EU innovation funds.[18] The European Clean Hydrogen Alliance is working to stimulate the rollout of production and the utilisation of hydrogen through the development of a green agenda and wants to build a concrete amount of hydrogen projects.[19] With regard to the upstream (production) of the hydrogen supply chain, the EU has set targets for domestic hydrogen production totalling 10 Mtpa and 10 Mtpa of import of the molecule by 2030. To achieve this, 100 GW of electrolyser capacity will be necessary of which 40% will be made in Europe.[20] Figure 4 shows locations of electrolyser manufacturing.

Figure 4 — Electrolyser Manufacturing Capacity vs Domestic Electrolyser Demand (GW)



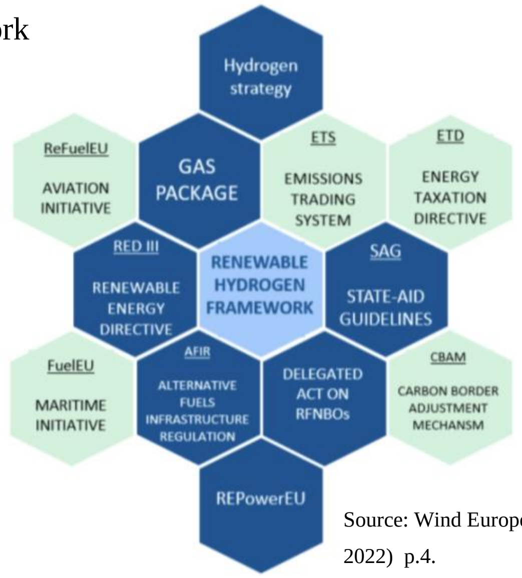
Source:Energy. Energy Hydrogen Cube 2023

[16] https://energy.ec.europa.eu/topics/energy-systems-integration/hydrogen_en
[17] https://www.europarl.europa.eu/thinktank/en/document/EPRS_BRI(2021)698781
[18] Appendix A – Interview 15 "Hydrogen Valley Expert"
[19] Key Action 1 - https://energy.ec.europa.eu/topics/energy-systems-integration/hydrogen/key-actions-eu-hydrogen-strategy_en
[20] Rystad Energy - Fierce Competition unfolding for green hydrogen technology – Whitepaper – US, EU, China, and India positioning to become major exporter – Hydrogen solution (2023) p.5.

With regard to the investments, the total investment cost to achieve the necessary domestic renewable energy production by 2030, will amount to roughly €335-471 billion (mostly consisting of private capital), of which €200-300 billion would be necessary to achieve additional renewable energy production.[21] To bridge the significant investment gap, the EHB was launched. The EHB will have access to €3 billion and aims at accelerating the hydrogen goals for meeting the REPowerEU targets. The EHB consists of four pillars, the first two being finance pillars for developing the EU domestic market and for the creation of international hydrogen imports; the third pillar targeting transparency and coordination; and the fourth pillar being based on the streamlining of public and private funding in the EU and in the international market.[22]

Where the EHB bears most of the financial brunt, the EU also supports hydrogen through the the German led H2-global initiative, with a German investment of €900 million. The aim of this scheme, which runs for a period of 10 years, is to attract additional volumes of hydrogen. The lack of sufficient hydrogen volumes is a critical issue for answering the research question of this paper. In 2024 the first deliveries shall take place based on 10-year contracts. This arrangement will facilitate financial aid for cost-competitive hydrogen projects that have to strictly comply with the rules as set out under the revised RED II.[23] The Netherlands has expressed its intent to join this scheme on October 13th, 2022, and officially joined in 2023.[24] [25] Figure 5 highlights the EU's hydrogen policies.

Figure 5 — EU Renewable Hydrogen Framework



Source: Wind Europe (July 2022) p.4.

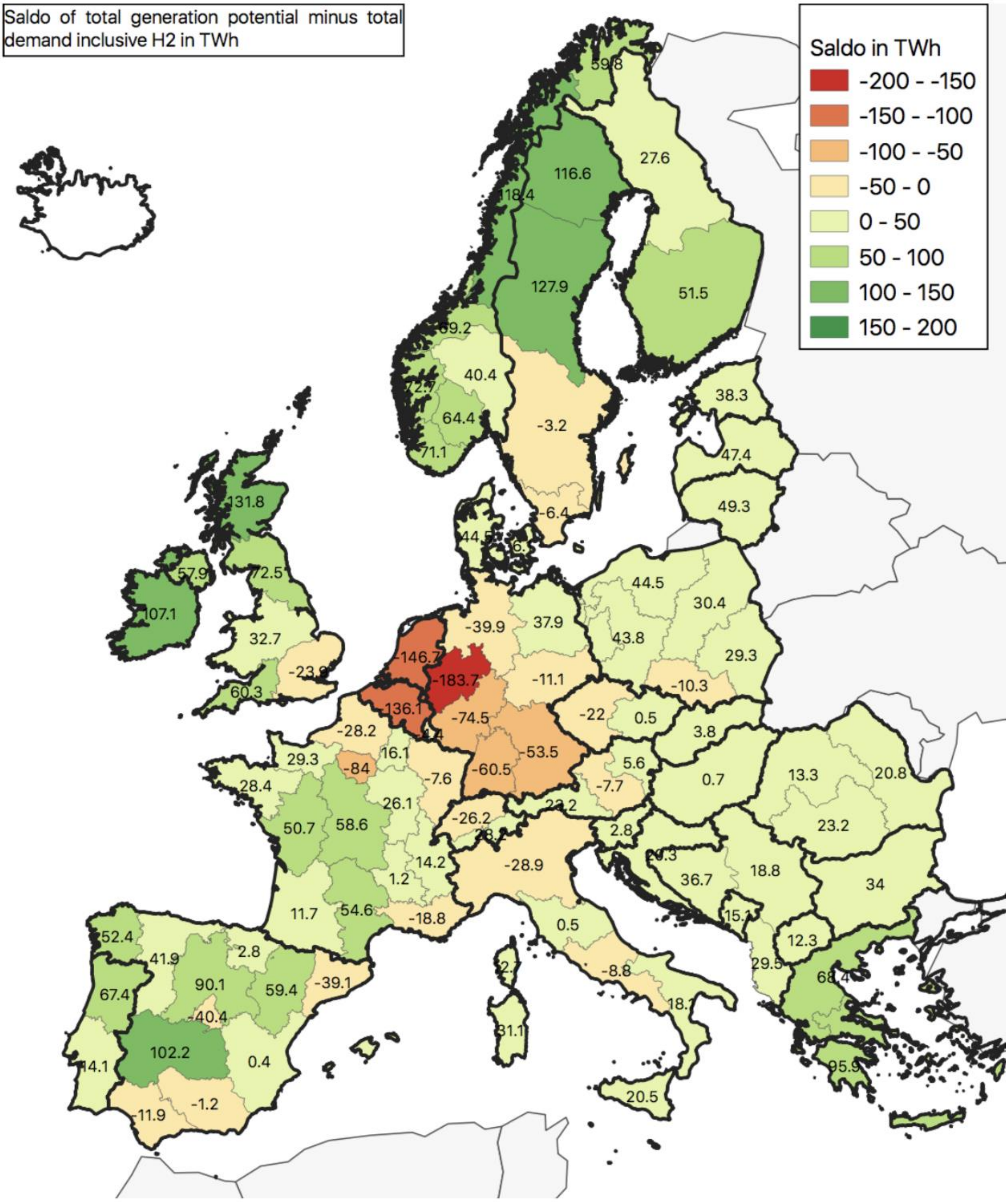
[21] https://energy.ec.europa.eu/news/commission-outlines-european-hydrogen-bank-boost-renewable-hydrogen-2023-03-16_en
[22] Ibid.
[23] https://ec.europa.eu/commission/presscorner/detail/en/ip_21_7022
[24] https://pemedianetwork.com/hydrogen-economist/articles/strategies-trends/2022/dutch-government-to-join-german-hydrogen-import-scheme/
[25] https://h2eg.com/h2-view-news-gasunie-bets-on-hydrogen-with-membership-of-the-h2global-foundation/

The Dutch Hydrogen Roadmap and Its Objectives

Having examined the global and EU policies pertaining to hydrogen, in this section, we delve deep into the workings of the Dutch hydrogen landscape, as articulated by the National Hydrogen Roadmap. The roadmap, developed by the Dutch government in concert with a wide array of public and private stakeholders, sets the course for the realisation of the Dutch hydrogen ambitions and climate targets and will aid in identifying the chances for the Netherlands to be a hydrogen leader in the EU.[26] The Dutch Climate Law makes it mandatory for the Netherlands to reduce its total GHG by 49% by 2030, and the roadmap places both low carbon hydrogen and renewable hydrogen at the heart of this endeavour.[27] The blue versus green hydrogen dichotomy is crucial for this paper as blue hydrogen could perpetuate the use of fossil fuels for societies, due to the required investments, physical infrastructure and the use of natural gas. Blue hydrogen is also not a key EU-goal. But, as observed in Figure 6, there is a huge shortage of renewable energy in the industrialised regions of the Benelux and the Ruhr Valley in Germany. For Grzegorz Pawelec, director of intelligence at Hydrogen Europe, this region are especially at risk of facing renewable energy deficits. According to Pawelec, there are several ways of alleviating these deficits. The first solution includes the use of all existing hydrogen production methods, including low carbon hydrogen. The second solution would be to increase the international trade of hydrogen and its derivatives.[28] Indeed, the Benelux and the Ruhr valley in Germany, could be described as the "throbbing heart" of the EU industry, but that comes at a price, as it will be more difficult to decarbonise. The dilemma that the Netherlands in particular faces, from a climate perspective, is that the rapid ramp-up of hydrogen is essential to the decarbonisation of its industry. Doubling down on hydrogen technologies could be a position born out of necessity, rather than out of luxury. Particularly distracting from this climate perspective is hydrogen's rising status as the "Swiss-army knife" of the energy transition. As one interviewee, put it succinctly: "The hydrogen lobby's main concern is pushing hydrogen, whether hydrogen actually has benefits in a sector or not is a secondary aim. If we would have to believe the hydrogen lobby, we could use hydrogen to brush our teeth."[29] It is this papers contention that hydrogen should be used where it has the most significant decarbonisation potential. The colour trade-offs are more elaborately discussed in Chapter 3.

[26] Dutch Hydrogen Roadmap (November 2022) p.3.
[27] Ibid. p.22.
[28] Pawelec, G. Hydrogen Europe Quarterly Q1 (2023) p.28.
[29] Appendix A – Interview 10 "Policy Advisor – International Advisory Association"

Figure 6 — Balance of Renewable Generation Potential and Demand with Electricity for Hydrogen in Europe 2050



Source: Wuppertal Institute. Infrastructure needs for deep decarbonisation of heavy industries in Europe (2020) p.18.

Production Methods

The Dutch hydrogen roadmap foresees a continued role of the existing SMR and Auto-thermal Reforming (ATR)-production techniques. While this seemingly goes against the long-term goal of the EU's green hydrogen ambitions, it will take time to fully replace grey hydrogen molecules with low-carbon or renewable alternatives. Additionally, one advantage of the SMR technology is its ability to reutilise carbon monoxide, for a variety of industrial applications. In any case, the Netherlands seeks a hybrid approach incorporating both SMR and ATR-techniques to address potential shortages resulting from intermittent availability of solar and wind energy. This strategy is particularly relevant for hydrogen off-takers in the five Dutch industrial clusters that would require an uninterrupted supply of the molecule.[30]

The Role of Electrolysers in the Dutch Hydrogen Landscape

Where SMR technologies provide a short-term solution for the Dutch decarbonisation goals, the role of the electrolyser is vital for the long-term green hydrogen production and decarbonisation goals of the Netherlands. An electrolyser serves as the essential device for electrolysis, the process by which water molecules are split into hydrogen and oxygen gases to produce hydrogen. Stressing the need for stability and security of supply for its industries, the Dutch government emphasises the importance of sufficient domestic electrolyser capacity. Furthermore, the government's ambitions for domestic electrolyser capacity align with the necessity of being able to convert peak renewable energy supply and store it in the form of green hydrogen. Storage, albeit arguably not a high priority use, is an additional advantage of the hydrogen technology.

To ensure a stable hydrogen supply-chain, it is furthermore critical to integrate the doubling down on offshore wind ambitions with strategically located electrolysers near industrial clusters. The roadmap acknowledges that the use of low-carbon hydrogen will remain a necessity in the Netherlands for decades together with other production methods of hydrogen production, such as hydrogen produced through nuclear means. It is not only the Netherlands that plans to produce hydrogen through low-carbon means (including nuclear).[31] Also, France would like to leverage its nuclear energy to help alleviate the shortage of low-carbon hydrogen. Phillipe Boucly, president of France Hydrogène, argues that: "Europe will need

[30] Dutch Hydrogen Roadmap (2022) p.32.
[31] Ibid. p.28.

both low carbon energy sources to achieve its climate goals, its energy independence and its industrial sovereignty with regards to decarbonised hydrogen. The United States has overcome this division, now it is Europe's turn."[32]

For the Netherlands, in any case, the offshore wind resource, provides some relief with regard to the forecasted shortages of hydrogen imports from third countries. The roadmap highlights the importance of establishing electrolysis capacity directly at sea near production facilities. This approach reduces the cost associated with transporting electricity, but also minimises the footprint in an already densely populated Dutch landscape. By leveraging offshore electrolysis technology, the Netherlands can capitalise on cost-efficiency and space optimisation, all the while harnessing the abundant offshore wind resources for sustainable hydrogen production.[33] Strategic placement of electrolysis capacity at sea complements the ambition of producing 80 Petajoules (PJ) of renewable hydrogen by 2030. To achieve this, the Dutch government plans to scale up the electrolyser capacity to 500 MW by 2025 and to 3-4 GW by 2030. A remarkable growth from the current operational capacity of around 3 MW. In order to achieve these targets, the operational electrolyser capacity would need to be increased by a factor thousand.[34] While the jury is still out with regard to whether this target will be met, it is nonetheless an essential step toward realising the Dutch and EU renewable production ambitions.

Next to the Herculean task of increasing the electrolyser capacity for hydrogen production, it is important to also look at the cost dynamics of the different types of hydrogen in the supply chain. Today, member states like the Netherlands and Germany rely heavily on grey hydrogen for their industries. Grey hydrogen's price sits at around €1.5 per kg, whereas blue hydrogen has a price tag of around €2-3 per kg. [35] The cost for green hydrogen varies depending on the scenario and whether short-term or long-term perspectives are taken into consideration. More optimistic estimations put a price tag of around €3-6 per kg.[36] The cost-competitiveness of green hydrogen is a crucial factor in determining the success and realisation of the Dutch hydrogen economy, as explored more elaborately in Chapter 2 and 3 of this work.

[32] Boucly, Phillipe - When Europe shoots itself in the foot on decarbonised hydrogen (2022) p.2.
[33] Dutch Hydrogen Roadmap (2022) p.31.
[34] https://www.tno.nl/nl/technologie-wetenschap/technologieen/elektrolyse/
[35] van Renssen, Sonja. "The hydrogen solution?" (2020): p.801.
[36] Chamber Letter: Fit-for-55%-pakket waterstof en Nationaal Waterstof Programma (March 2022) p.2.

The Use of Green Hydrogen

The successful adoption of hydrogen as a clean energy source, depends largely on the synergy between infrastructure and the use of green hydrogen. The Dutch industry, which currently consumes a substantial amount of grey hydrogen, plays a significant role in this transition, with the presence of the so-called hard-to-abate sectors (sectors that are especially difficult to decarbonise), like the Dutch steel and chemical industries. The Netherlands is the second-largest consumer of grey hydrogen in the EU.[37] The Dutch industry consumes roughly 180 petajoules (PJ) or 50 terrawatt-hour (TWh) of hydrogen per annum.[38] Here, it is important to state the problems with accelerating the use of low-carbon or renewable hydrogen for these hard-to-abate industries. The main obstacles for the end-use of low-carbon or renewable hydrogen are not only the costs of renewable and low-carbon hydrogen production, but also pertain to regulatory obstacles. The merit order of where hydrogen should be used first is an important field of inquiry (as shown in Table 3). One of the interviews conducted for this paper highlights the need for the Dutch government to be more precise with regard to where to use its molecules. The interviewee, advocates for increased hydrogen use in the steel, cement, aviation, and heavy-duty vehicle sector. The Dutch roadmap also includes targets for light mobility, which given the scarcity of the molecule is considered a controversial use case.[39]

Table 3 — Applications Where the Use of Hydrogen is Most Needed

Green molecules needed?	Industry	Transport	Power sector	Buildings
Uncontroversial	· Reaction agents (DRI steel) · Feedstock (ammonia, chemicals)	· Long-haul aviation · Maritime shipping	· Long-term storage for variable renewable energy back-up	· District heating (residual heat load *)
Controversial	· High-temperature heat	· Trucks and buses ** · Short-haul aviation and shipping	· Absolute size of need given other flexibility and storage options	
Bad idea	· Low-temperature heat	· Cars · Light-duty vehicles		Individual buildings

* After using renewable energy, ambient and waste heat as much as possible. Especially relevant for large existing district heating systems with high flow temperatures. Note that according to the UNFCCC Common Reporting Format, district heating is classified as being part of the power sector.

** Series production currently more advanced on electric than on hydrogen for heavy duty vehicles and busses. Hydrogen heavy duty to be deployed at this point in time only in locations with synergies (ports, industry clusters).

Source: Agora Energiewende 12 Insights on hydrogen. (2021) p.8.

[37] CE DELFT – TNO: "50% green hydrogen for Dutch industry" (2022) p.4.
[38] Dutch Hydrogen Roadmap (2022) p.62.
[39] Appendix A – Interview 8 "Hydrogen specialist of a Dutch Technical University"

With regard to the perspectives of the major Dutch industrial clusters, who have stated that renewable and low-carbon hydrogen will play an important role in their sustainability strategies, yet for whom a direct transition from grey hydrogen towards green hydrogen is considered to be unrealistic.[40] As a study conducted for the roadmap highlights, the road ahead for hydrogen within the Dutch decarbonisation goals is fraught with difficulties due to limits placed on the future domestic hydrogen supply.[41] As imports will continue to play a high role in higher end demand much of the decarbonisation potential of hydrogen will depend on the imported volumes of the molecule.

With regard to the industrial actors present in the Netherlands, they prioritise a transition from grey hydrogen to blue hydrogen, before eventually shifting towards renewable hydrogen. Estimates show that 28% of total grey hydrogen use in industry can be decarbonised without substantial modifications to current industrial practises. This is at odds with Article 22a of the RED III directive, which obligates member states to utilise green hydrogen for 42% of their total hydrogen consumption by 2030.[42]

Import for the Netherlands: Enhancing the Trading Hub through Hydrogen

The Dutch ambition to become a prominent energy hub in North-Western Europe depends on the strengthening of its import position and its ability to act as a transit corridor for hydrogen and its derivatives. A representative from an infrastructure and transportation company perceives the Dutch hydrogen role as a combination of an importing and exporting country.[43] Such a strategic repositioning aligns well with the role of the port authorities. In keeping such a vision, the importance of strategic collaborations with various partners is significant. One interview identified potential partners as those nations that are part of the 'Esbjerg declaration' and the 'Oostende declaration'. Both declarations are signifiers of the cooperation between North-Western European hydrogen producers of which the Netherlands is also a member.[44]

[40] Dutch Hydrogen Roadmap (2022) p.64.
[41] CE DELFT – TNO: "50% green hydrogen for Dutch industry" (2022) p.5.
[42] Ibid. p.8.
[43] Appendix A – Interview 3 "Representative of infrastructure and transportation company"
[44] Ibid.

With regard to the strengthening of hydrogen alliances, the Dutch Climate and Energy Minister, Rob Jetten has established Memoranda of Understanding (MoU) with diverse entities including firms, ports, knowledge institutes and nations such as Portugal, Chile, Uruguay, Canada, Namibia, and more recently, the UAE, Oman, Morocco, South Africa, Australia and Curaçao. Jetten addresses the importance of the two-hydrogen import-terminals located in Rotterdam and in the North Sea area as key facilitators of this hydrogen trade. But in the end, it is not the climate minister who decides how the hydrogen trade will unfold, this responsibility will be delegated to private companies. The government's role will be confined to creating the right conditions to facilitate the imports. [45]

Market Development

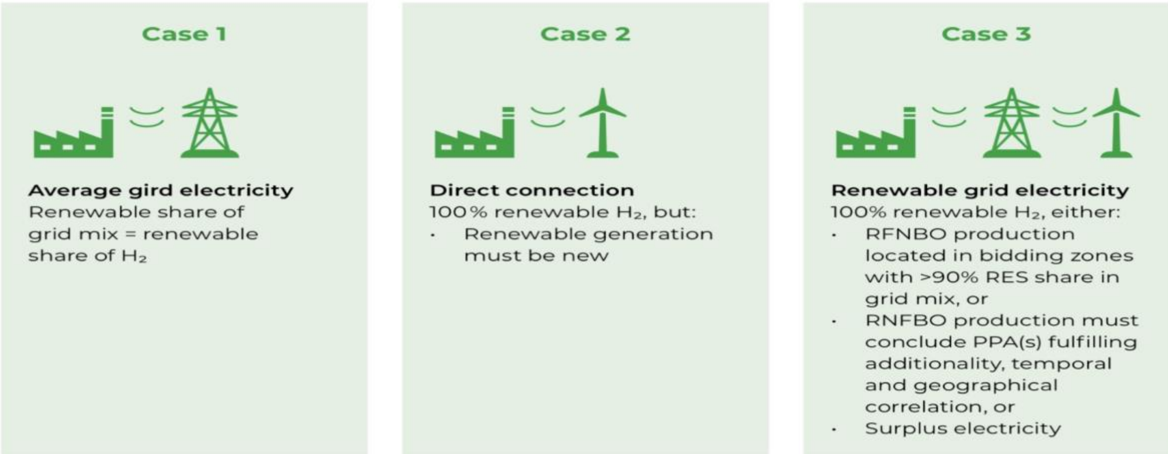
Alongside the production, infrastructure and import goals, the roadmap stresses the necessity of rapidly developing a robust hydrogen market and for sufficient renewable energy sources to be secured. The roadmap also indicates that after government subsidies, the market has to reach maturity on its own. This requires the launching of trading platforms, certification schemes and demand stimulation, as well as methods for calculating the whole hydrogen CO2 lifecycle.[46] As the second largest user of grey hydrogen in the EU, the Netherlands has taken steps to address these challenges. It has initiated its own certification process (HyXchange), providing a guarantee of origin for hydrogen produced from renewable sources, following EU guidelines. To further support the development of the hydrogen market, the Dutch initiative HyXchange was launched with the support of Gasunie and four seaports. Its goal is to establish a trading hub for hydrogen that leverages critical infrastructure already in place.[47]

The roadmap lays out the key benefits that the budding hydrogen economy will bring to the Netherlands, as well as why this is of importance for the Dutch decarbonisation goals.[48] Not only will the Dutch infrastructure for natural gas remain in place, but it will be repurposed for transport and trade of hydrogen.[49] Currently, a large part of the Dutch hydrogen is produced using natural gas. Demand for such hydrogen is huge in the Dutch industry, especially in the refinery, fertiliser, and the chemical industry, and therefore the decision to set targets of 42%

[45] Dutch Hydrogen Roadmap (2022) p.41.
[46] Ibid. p.28.
[47] Ibid. p.38
[48] Ibid. p.38
[49] Dutch Climate Agreement – (2019) p.32.

for green hydrogen or Renewable Fuels of Non-Biological Origin (RFNBOs) by 2030 and 60% for 2035 are a game changer.[50] Additionally, the partners of the roadmap have the goal of a 600 MW electrolyser capacity that has to grow and be adapted to the growing offshore wind and solar parks and the national hydrogen transport grid. In order to ensure that green hydrogen does not 'cannibalise' the electricity grid, renewable energy technologies, like solar and wind, have to be scaled up massively in the Netherlands. On the short term, hydrogen producers under the 'Delegated Act on Additionality' would be exempted to the rule if renewable energy is purchased using a power purchase agreement (Figure 7).[51]

Figure 7 — Different Cases for Hydrogen Production



Source: Guidehouse "Facilitating Imports" (October 2022) p.25.

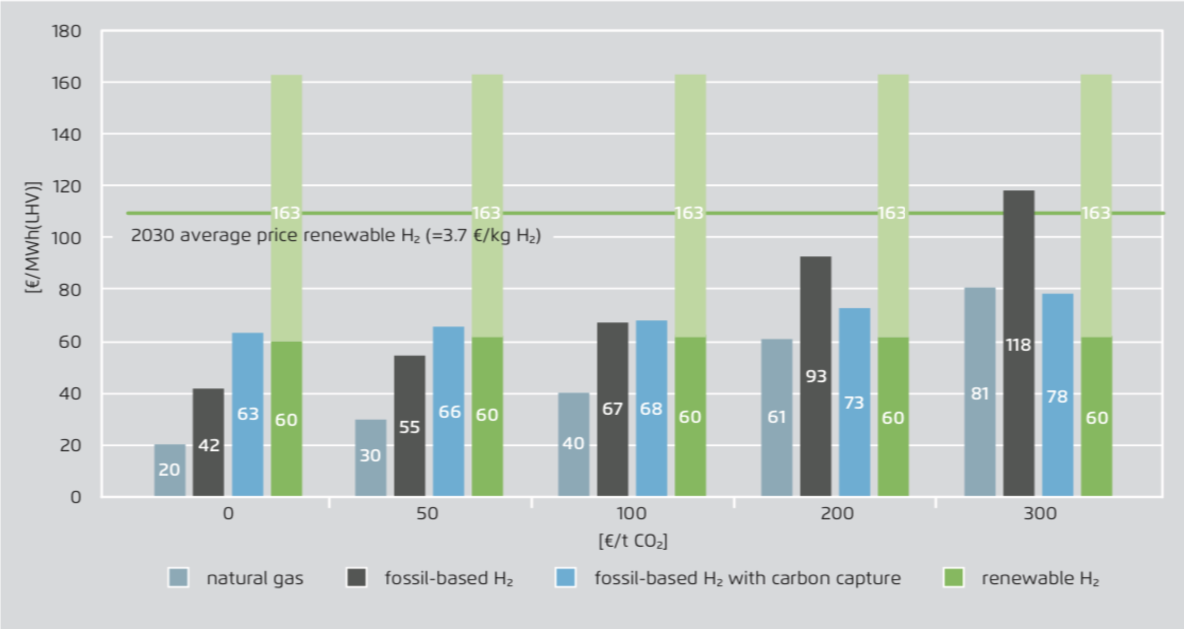
Subsidy Instruments to Stimulate Market Growth

The roadmap foresees the use of subsidy instruments to guide the nascent hydrogen market and to nurture growth. This will be the reality at least towards 2030, after which the market should become more independent and stable. Currently, the Dutch Climate and Energy Minister has the ambition of having achieved more than 500 MW of internal electrolysis capacity by 2025. This is made possible through subsidies that target production and through the stimulation of the use of renewable hydrogen in refineries until at least 2030. Additionally, the minister of Climate and Energy expects to be able to subsidise 1 GW of electrolysis capacity. 800 – 1000 MW of electrolysis capacity will be subsidised for projects belonging to the IPCEI's.[52] For the second wave in this subsidy process, €783,5 million will be shared between different electrolysis projects. However, a study by Machiel Mulder of the University of Groningen, shows how hard it will be to achieve sufficient electrolyser capacity without subsidy schemes. The research shows that under current market circumstances in the

[50] CE DELFT – TNO: "50% green hydrogen for Dutch industry" (2022)
[51] https://hydrogen-central.com/what-additionality-why-hydrogen-industry-need-hycap/
[52] Progress Hydrogen Policy – Jetten. R. Climate and Energy Minister (2022) p.3. https://open.overheid.nl/documenten/ronl-7c7b4555e9e760329c2a83ebef633fdac833dc18/pdf

Netherlands, investments in a 100 MW electrolyser plant needs about 100% of its investment costs subsidised to break even. This is due to the limited number of hours when electricity prices are low enough for such a plant to be operational.[53] The EU-Emission Trading Scheme (ETS), meanwhile, is anticipated to further drive the demand for renewable hydrogen beyond 2030. As seen in Figure 8, the impact of carbon pricing will progressively start to close the cost gap between grey and green hydrogen.

Figure 8 — Impact of Carbon Pricing on Hydrogen Production Cost by 2030



Source: Guidehouse (2021)

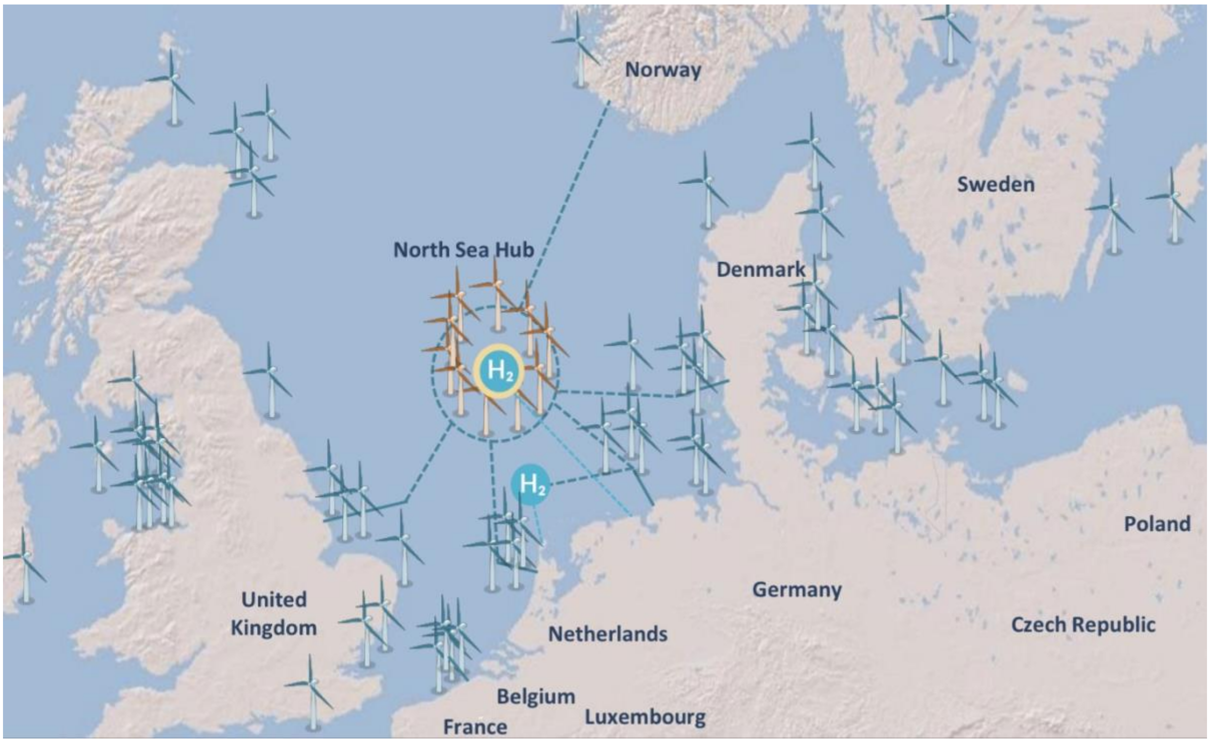
To conclude this chapter, the Dutch hydrogen sector finds itself in a dynamic phase of development and growth. The roadmap offers a strategic vision and a detailed action plan to transition towards a green hydrogen economy and to realise the decarbonisation goals. The plan emphasises the role of electrolysis and the need for sufficient renewable energy sources, next to the development of the infrastructure and a strong Dutch import position. The implementation of hydrogen-market development tools and subsidy instruments further accelerates the growth of the hydrogen market. However, significant challenges lie ahead such as the cost and the availability of green hydrogen. Building on this foundation, the following chapter delves into the accelerators that drive the Dutch hydrogen supply chain. A critical analysis of these accelerators facilitate important insights in how much of a role the Netherlands could play in the future EU hydrogen landscape and whether it can be considered to have a leading role.

[53] Veenstra, Arjen, and Machiel Mulder. "Economics of hydrogen production." (2023) p.5.

Chapter 2: Favourable Winds – Turning the Wheel

As the Netherlands is transitioning towards a low-carbon future, what are the most significant accelerators that are turning the Dutch hydrogen wheel in the Netherlands today? This chapter highlights the accelerators for the Dutch hydrogen supply chain. Figure 9 shows the potential of combining offshore wind facilities with North-Western European partners for the creation of a North Sea Hydrogen Hub, in which the Netherlands is expected to play a vital role.

Figure 9 — The North Sea Hydrogen Hub



Source: Wind Europe (2022)

The North Sea Energy Hub

In the context of the Netherlands, a key factor for accelerating the growth of the emerging hydrogen trade lies in its ability to establish itself as the energy hub for North-Western European countries and hydrogen exporting nations. The Dutch government recognises the significance of European collaboration in establishing international hydrogen supply chains, enabling diversification and sharing potential risks as emphasised by Stam.[54] The Dutch ambition to become an international player in the hydrogen scene can be illustrated by the creation of a hydrogen envoy, the first country to do so.[55] The Dutch government aims at

[54] Stam, Roelof, Coby van der Linde, and Pier Stapersma. "The Netherlands as a Future Hydrogen Hub for Northwest Europe: Analysing Domestic Developments and International Engagement." (2023). p.13.
[55] Ibid. p.12.

leveraging its current energy hub function to position itself as a European hydrogen transit hub.[56] To lead in the hydrogen energy transition, the Netherlands must capitalise on its strengths: robust domestic renewable production, a strategic import and export location, extensive pipeline and natural gas infrastructure, maritime connectivity, terminal and logistics infrastructure, alongside a robust off-take base. All of this would have to come together to create an ideal import, transit, and production hub.[57] As demonstrated in Figure 10, which outlines the planned EU hydrogen import terminals, the Netherlands' strategic location is an essential component. Other potential benefits for the Dutch candidacy as the EU's hydrogen frontrunner, includes storage capacities for hydrogen in salt caverns and the expertise in the handling of molecules as a legacy of the Groningen gas field.[58]

Figure 10 — Plans for Hydrogen Import Terminals across the EU

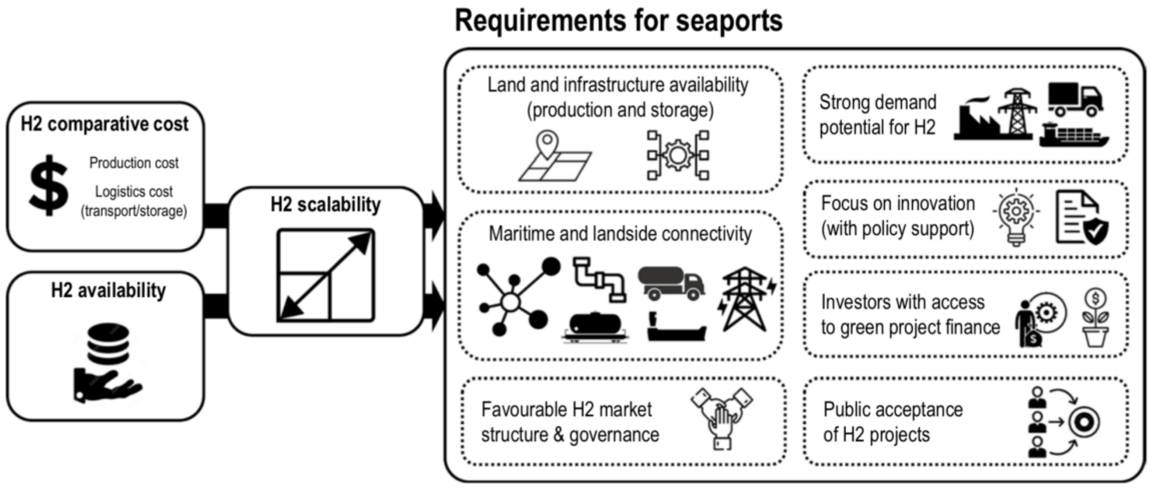
Source: Guidehouse. Assessing the benefits of a pan-European hydrogen transmission network (2021) p.50.

[56] Ibid. p.5.
[57] Notteboom, Theo, and Hercules Haralambides. "Seaports as green hydrogen hubs: advances, opportunities and challenges in Europe." Maritime Economics & Logistics 25.1 (2023): p.5.
[58] Appendix A, Interview 1 "C-level representative of a Dutch Port Authority"

The Dutch Seaports

The Netherlands is scaling-up for a large-scale hydrogen future, capitalising on the geographical location of its ports and its history as a natural gas trading hub. The EU intends to import half of its green hydrogen from non-EU countries, a development that the Netherlands wants to take advantage of by readying its ports, which will be the central hub for this envisioned hydrogen trade. Figure 11 shows the requirements for ports to serve as green hydrogen hubs. The Rhine-Scheldt Delta port system, encompassing the two largest ports of Europe, Rotterdam and Antwerp-Bruges, as well as Europe's fourth largest port, the Amsterdam/IJmuiden port, constitutes a significant share of the EU's port system in terms of volume, representing 27 % of all port throughput processed in the EU.[59] Moreover, the Port of Rotterdam, is a part of the Antwerp-Rotterdam-Rhine-Ruhr-Area, which accounts for 40% of the total petrochemical output in the EU.[60] A significant advantage for the Dutch hydrogen case is the already existing hydrogen grid, consisting of a 900km pipeline that connects Rotterdam to Antwerpen and Dunkirk.[61]

Figure 11 — Key Requirements for Ports to Serve as Green Hydrogen Hubs



Source: Notteboom, Theo (2023) p.18.

In particular, the port of Rotterdam, Europe's largest seaport and a neighbour to the world's leading industrial hubs, stands as the primary locus of the envisioned hydrogen trade. The port has set ambitious targets to supply the EU with 4.6 Mt of hydrogen by 2030, including 2.5 GW of electrolysis capacity by that year. Of this total, 600,000 tons of hydrogen would be produced on site, with the remaining 4 Mt imported.[62]

[59] Notteboom, Theo (2023): p.11.
[60] Stam, Roelof, (2023) p.5.
[61] Van de Graaf, Thijs, et al. (2020) p.3.
[62] Mullen, Elizabeth. "Financing the Green Hydrogen Economy." (2023) p.5.

The Dutch government recognises these opportunities. The Dutch Ministry of Infrastructure and Water-engineering envisions large-scale ammonia imports — the most likely carrier of the hydrogen molecule — as a crucial strategy to maintain the prominence of the Dutch seaports as a trade-hub for critical minerals, resources and energy, thereby fostering a competitive business climate. Moreover, the Chemelot chemical cluster could, over time, be supplied with ammonia via the developing Delta Rhine Corridor, a cluster of pipelines that is currently in development. This potential increase in ammonia transport via this corridor could also cater to demand from Germany, further bolstering the strategic importance of the Dutch seaports.[63]

The Offshore Wind Potential

The Dutch part of the North Sea, spanning approximately 58.000 km², offers a remarkable potential for offshore wind energy. The government intends to enhance this capacity, given its favourable location in the Northwestern European region. The shallow waters, coupled with port connectivity and proximity to industrial clusters, make it an ideal location for offshore wind production.[64] Exploiting this offshore wind potential is key to bolstering the Dutch position in the hydrogen landscape.

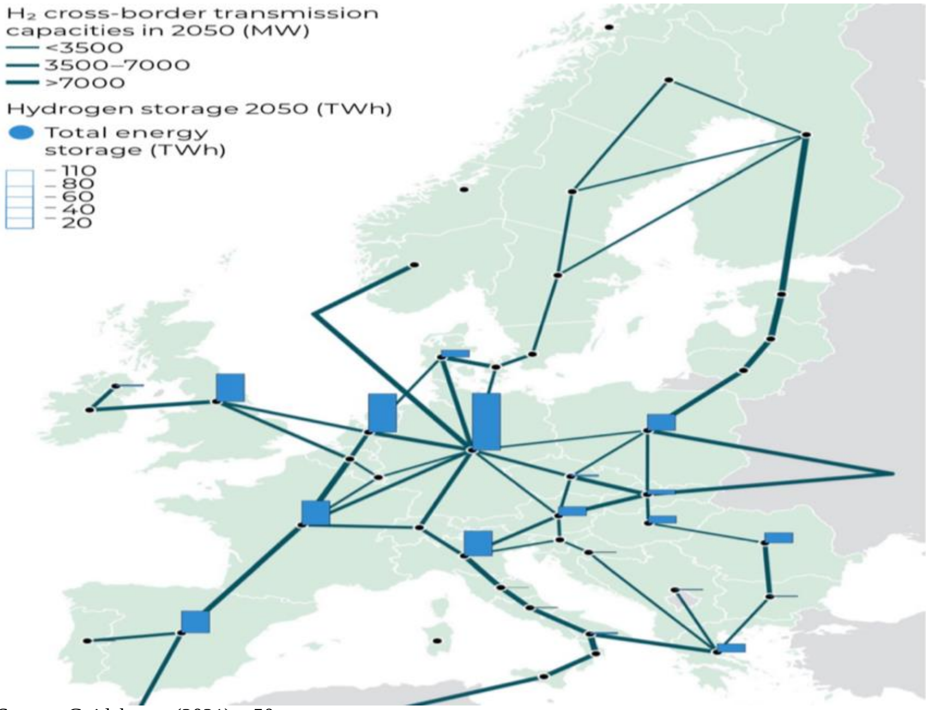
In particular, the Groningen Seaport in the northern part of the country is emerging as a pivotal offshore wind conversion point. This development further strengthens this seaports position as a hub for hydrogen energy.[65] Various projects are under way, including Shell's Holland Hydrogen 1, which aims at installing a 200 MW electrolyser in Rotterdam on the second Maasvlakte and NortH2, in the north of the Netherlands, which aims at supplying 4 GW of hydrogen by 2030, and 10 GW by 2040, under a consortium run by Shell, Equinor, RWE, ENECO, Gasunie and Groningen Seaports.[66] The great offshore wind capacity not only accelerates the Dutch hydrogen ambition, but also serves as a catalyst for enhanced cooperation with other North-Western countries. Although the offshore potential of the Netherlands is substantial, nonetheless intensive debates remain with regard to where actors want to use this wind energy, whether for green electricity or for the production of molecules.

[63] Chamber letter of the Dutch government: Environmental safety study report future flows of hydrogen-rich energy carriers p.1.
[64] Stam, Roelof, (2023). p.5-6.
[65] Ibid. p.5
[66] Ibid p.7.

Storage: Natural Gas Fields and Salt Caverns

The Netherlands has a rich supply of empty salt caverns and gas fields, which are suitable for storing CO2 – a byproduct of blue hydrogen. The Porthos project, based in the Port of Rotterdam, exemplifies this approach. Although currently delayed due to a lawsuit by the Mobilisation for the Environment, Porthos aims at transporting and storing CO2 offshore, contributing to significant emissions reductions and supporting the growth of the Dutch hydrogen economy. As Roelof writes: "CCS provides a relatively quick solution to decrease emissions considerably and plays a role in the Dutch national carbon reduction strategy". Following this, the Dutch ministry for Climate and Energy published a letter which declares that it would take part of the financial risk associated with the project as it is considered vital for meeting the Dutch 2030 climate goals.[67] Figure 12 shows the cross-border transmission and hydrogen storage capacity.

Figure 12 — Cross-border Transmission and Hydrogen Storage Capacity



Source: Guidehouse (2021) p.50.

[67] Ibid. (2023). p.6.

Existing Infrastructure

Since the discovery of the Groningen natural gas field in 1959, the Netherlands grew to become Europe's largest natural gas producer connecting the Netherlands, Belgium, Germany, and France. As Stam argues, "The Dutch have established institutional arrangements for the European Gas Market. These experiences can provide valuable lessons for developing a hydrogen energy hub in the Netherlands. When the finite nature of the Groningen field's natural gas supplies became clear, it spurred a shift in the Dutch strategy. Instead of focusing solely on production, the Dutch diversified towards import strategies in the 2000s". According to Stam, this strategic shift has enabled the Netherlands to diversify its supplies away from Russian fossil fuels and gives the Dutch hydrogen position a head-start. In 2021, the Dutch government decided to refurbish its gas pipelines for hydrogen transport.[68] It is expected that the Dutch hydrogen backbone will be ready by 2027. The idea is to facilitate easy transport of the hydrogen molecule to connect all industrial clusters in the Netherlands with the possibility of export to Germany and Belgium. It is expected that the Dutch hydrogen backbone will have a capacity of up to 10-15 GW by 2030.[69] [70] The Ministry of Economic Affairs and Climate policy issued a mandate to a Gasunie subsidiary (HyNetworkServices), a gas-infrastructure and transportation company owned by the state, to kick-start the national hydrogen transport grid. Gasunie already operates 11,700 km of natural gas grid, of which 8,700 km are located inside the Netherlands and the other 3,000 km are located in Germany. A C-level port authority argues that the Dutch infrastructure is critical to the whole hydrogen endeavour. Gasunie, network operators and port authorities are the front runners in shaping the Dutch hydrogen supply-chains. After that, it is expected that the chemical industry, like HYCC and Shell, will actively contribute to the supply chain, as they see that there are no alternative and because the infrastructure will be there.[71] A policy advisor interviewed on this topic stresses the importance of retrofitting the current natural gas infrastructure, but stresses that there is as of yet, little to no talk regarding the lower distribution networks, the smaller pipelines that would go through the Dutch neighbourhoods.[72] Although this could be perceived as a disadvantage, it is this thesis contention that this ensures a higher chance that the hydrogen molecule flows towards the industries.

[68] Stam, Roelof, (2023). p.7.
[69] Ibid. p.14-15.
[70] Ministry of Economy & Climate - Development of hydrogen transmission grid - June 29, 2022 p.2.
[71] Appendix A – Interview 6 "C-level Port Authority"
[72] Ibid. – Interview 9 "Policy advisor working for a Dutch energy consultancy"

One example of why the Dutch infrastructure is an accelerator is the Delta Rhine Corridor project. This is a bundle of pipelines that will connect the Port of Rotterdam with the petrochemical cluster Chemelot and the industrial German Rhineland region. The project is run as a private-public partnership with a consortium of Shell, Port of Rotterdam, BP, RWE, Thyssenkrup, LyondellBasell, Heidelberg Cement, Attero and Chemelot.[73] As the project would connect the majority of the Dutch industrial clusters (Moerdijk, Geertruidenberg, Chemelot, and NRW) that are located in close-vicinity of the Delta Rhine Corridor, these hard-to-abate sectors could increasingly be decarbonised through the use of clean and low-carbon hydrogen. According to Allard Castelein, the CEO of Port of Rotterdam: "The Delta-corridor is the key for inland industry clusters to bring their processes in line with the Paris climate goals and the European Fit-for-55 programme. The timely supply of hydrogen in combination with CO2-storage opportunities truly helps the industry to drastically reduce their emissions. Connecting national and international industry cluster via Rotterdam is the most efficient route. The corridor is also beneficial for the national economy and the future earning capacity of the Netherlands. I am delighted to see that more partners are joining this strategic important public-private partnership."[74] Thus, the Delta Rhine Corridor can be seen as an example of the Dutch hydrogen infrastructure potential.

The Hydrogen Trade with Germany

The 2019 Joint Declaration of Intent on the Energy Transition was signed by the Climate and Energy ministries of the Netherlands and Germany and solidified ambitions for closer energy cooperation. This includes a strong cross-border offshore wind project development as well as for infrastructure development in the North Sea area.[75] It is from the same intent that the HY3 project was launched, a project consisting of the Netherlands, Germany and the North-Rhine Westphalian state, to decarbonise industry through hydrogen. An interview conducted on the cross-border hydrogen relationship between Germany and the Netherlands highlight the mutual interests that both countries have in developing the hydrogen backbone between both EU member states. Both countries have strong mutual interests with regard to import, cross-border hydrogen infrastructure and both seek to become hydrogen technology exporters in next-generation electrolysers. The interview highlights that the Dutch-German hydrogen partnership is mostly without constraints as the demand for the hydrogen molecule is so high

[73] https://www.portofrotterdam.com/en/news-and-press-releases/broad-industry-support-for-delta-corridor-project
[74] Ibid.
[75] Hy3 – Large-scale Hydrogen Production from Offshore Wind to Decarbonise the Dutch and German Industry (2022) p.10.

that the countries are not competitors within the hydrogen supply chain. The Netherlands joining the German H2 global initiative is also perceived by the interviewee as a sign of such alignment.[76] The cooperation between Germany and the Netherlands in the field of hydrogen would additionally act as a lighthouse project, an indication of what a transnational hydrogen supply chain would look like.[77] Both countries have a strong natural gas infrastructure that can form the backbone of the coming hydrogen market. The HY3 study shows the potential for cooperation through which the Dutch and German offshore wind energy could be utilised to produce hydrogen for the Dutch and German industrial clusters.[78] Through this initiative the Netherlands would see its position as a key-transit hub reinforced.

As Germany plans to import half of its hydrogen demand in the near-future from or via the Netherlands this is a clear accelerator for the Dutch hydrogen ambitions.[79] It is expected that the total Dutch hydrogen production from offshore wind by 2050 would amount to between 54 and 139 TWh yearly, whereas for Germany, at around 37-100 TWh, with an expected import of hydrogen of around 6-21 TWh for 2030 and at around 162-310 TWh by 2050.[80] Additionally, the H2 Global import scheme, a German initiative, which the Netherlands has joined, will aim to connect the Port of Rotterdam, Hamburg, and Duisburg to attract major hydrogen flows.[81] The significant hydrogen demand of Germany and the Netherlands combined ensures that there are no expected problems with regard to the off-take of the green molecule when it arrives in North-Western Europe.[82] This strong demand side acts as an accelerator for the Dutch hydrogen supply chain. The only problem with which the Netherlands could see its hydrogen export position dampened vis-à-vis Germany could be, in the words of a policy advisor working for an energy consultancy, that the tempo is lost, and that Germany will develop alternative routes for hydrogen imports, which could take the form of the German Hamburg Port or Belgian Antwerp port.[83] Other potential hydrogen corridors could potentially run through France and Austria.

[76] Appendix A – Interview 16 "H2 German-Dutch Cross border Expert"
[77] Hy3 –(2022) p.10.
[78] Stam, Roelof, (2023). p.12.
[79] Ibid. p.12.
[80] https://www.tno.nl/nl/newsroom/2022/03/hy3-project-weg-nederlands-duitse/
[81] Stam, Roelof (2023). p.12.
[82] Appendix A – Interview 2 "Representative of an International Energy Company working on a H2 project in the Netherlands"
[83] Ibid. – Interview 9 "Policy advisor working for a Dutch energy consultancy"

Stakeholder Mapping

The stakeholder field of the Dutch hydrogen market is complex in terms of a variety of strongly divergent internationally operating actors, a highly engaged government, pressure from NGO's, economic opportunities, and new technological hydrogen applications in nascent markets. National and regional NGO's have a different stake in hydrogen than the diverse industrial groups and organisations. On a individual company level, we see that fertiliser companies have different interests than, for example, the steel industry, while in the energy domain, utilities are positioned differently than production and trade companies within the hydrogen market.[84] [85]A thorough and precise stakeholder analysis is therefore of the essence for this paper. While such precise stakeholder analyses exist within energy companies in the Dutch hydrogen landscape, those are often produced with the help of larger consultancies. These capital-intensive studies are not usually made public. Regardless, we attempt to juxtapose the diverse stakeholders' interests on an aggregated level and attempt to analyse how these stakeholders behave, either alongside or against each other, in order to examine the interplay of forces that influence the opportunities and threats for the Dutch hydrogen market.

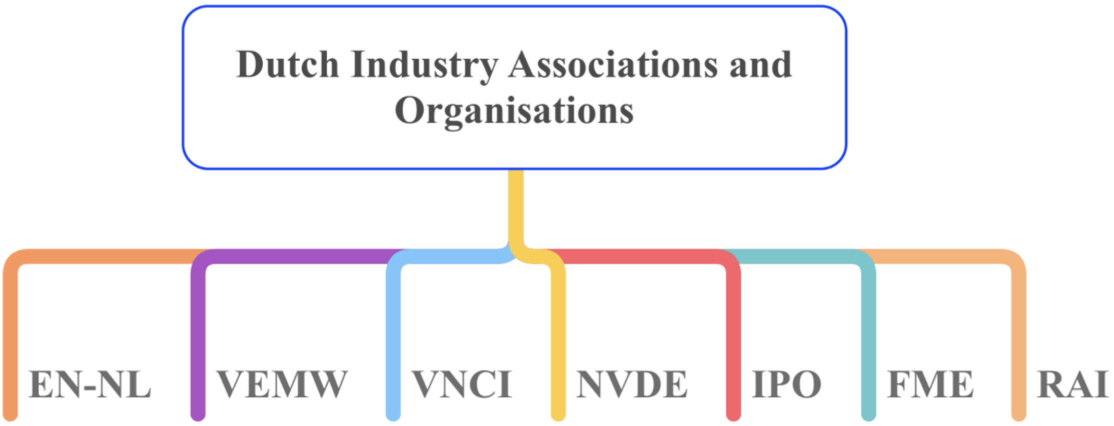
Industry Associations and Organisations

Within the market organisation, as observed within the Netherlands, the industry is crucial, considering that these companies, after receiving ramp-up support from the government, will have to advance a new business-model for the development of blue and ultimately green hydrogen. Here it is observed that the industry, in addition to the individual lobby and marketing activities, are also collectively organised through four larger and several smaller Dutch interests and lobby organisations. It is noteworthy that all larger companies are almost always member of different interest organisations, and in the case of dominant market players, they are often members of all interest organisations. For those companies, that often have a fossil background, these organisations are of importance, as they have a higher credibility than individual corporations such as Shell or RWE.[86] On the basis of websites and mission statements of these interest organisation, it can be said that they prioritise the collective members' interest in their entire thinking and actions. For hydrogen associations this is primarily translated into hydrogen promotion. Industry associations and organisation

[84] https://www.saurenergy.com/solar-energy-news/tata-steel-partners-with-three-dutch-companies-for-hydrogen-based-steel
[85] https://www.yara.com/corporate-releases/orsted-and-yara-seek-to-develop-groundbreaking-green-ammonia-project-in-the-netherlands/
[86] Junk, Wiebke Marie. "Co-operation as currency: How active coalitions affect lobbying success."(2020) p.873.

(Diagram 1) almost always have a lobbying function towards regional, national, and European governments; strive to effectively present their arguments in generic and industry media; make efforts to positively influence the societal acceptance of their members' interests; have their own knowledge and content gathering, with the output shared with individual members; prefer to profile themselves based on societal and environmental interests, with less emphasis on the underlying corporations.[87]

Diagram 1 — Dutch Industry Associations and Organisations



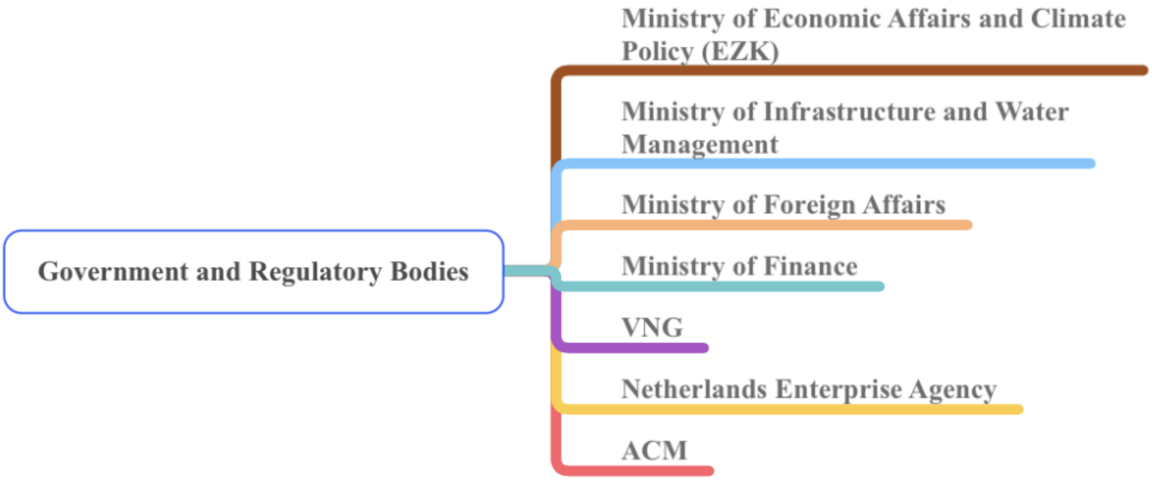
Government & Regulatory bodies

The Ministry of Economic Affairs and Climate Policy is positioned differently in the hydrogen landscape as compared to the Ministry of Infrastructure and Water Management and to a lesser extent the Ministry of Foreign Affairs, Finance or even Foreign Affairs. The Ministry of Economic Affairs and Climate Policy holds significant policy and administrative dominance, in part because it has a separate minister for the Environment and Climate, Rob Jetten, who has his own budget of 35 billion and exercises above-ministerial control over the allocation of climate-related funds.[88] Regional governments naturally focus more on local and regional issues, including greening of the industry, preservation of regional natural areas, and regional employment aspects. However, some general observations can be made about the position of governments in this stakeholder field: Government and regulatory bodies (Diagram 2) all aim to bring climate goals closer through active hydrogen promotion; are

[87] Palazzo, Guido, and Andreas Georg Scherer. "Corporate legitimacy as deliberation: A communicative framework." (2006) p.73.
[88] https://www.government.nl/latest/news/2022/09/20/2023-central-government-budget-focuses-on-purchasing-power-and-major-future-challenges

willing to allocate societal resources for this purpose; seek combinations of national and European subsidy sources; want the hydrogen market to eventually function as an independent market; are open to public-private collaborations, as long as they do not involve government interference in the market; are extremely cautious about favouring one or a few market parties; and try to navigate between short-term political interests and long-term societal interests.

Stakeholder Diagram 2 — Government and Regulatory Bodies



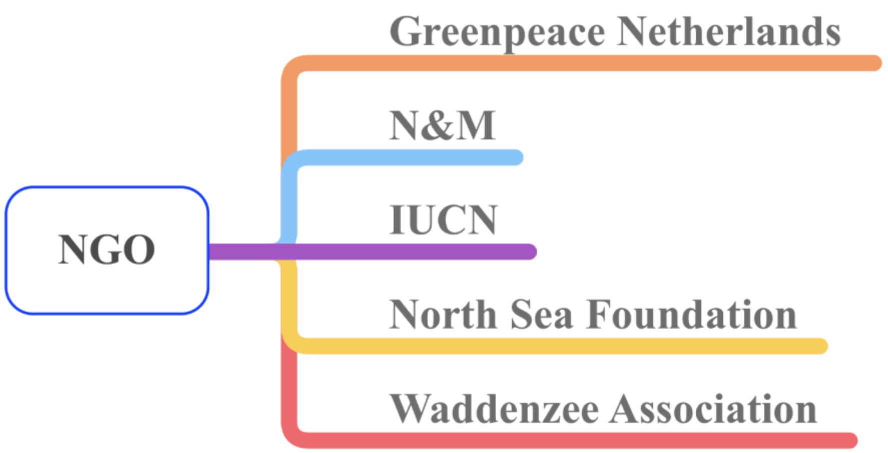
NGOs

As non-profit organisations, NGOs are relatively closer to the government than to the business sector. The most prominent NGOs are those with a focus on the preservation of nature. For example, IUCN Netherlands seeks to minimise the adverse effects of energy extraction, production, and distribution on Natura 2000 areas.[89] [90] On the other hand, the North Sea Foundation (Stichting Noordzee) aims to minimise the impact on marine flora and fauna in the North Sea region.[91] While the Waddenzee Association primarily focuses on a subset of the North Sea domain, namely the Dutch Wadden Islands, which are part of UNESCO's World Heritage.[92] The influence of these NGOs on the pace of the hydrogen transition should not be underestimated. Opposition from local and regional NGOs (and residents) against the construction of an offshore electricity cable through the Wadden Island of Schiermonnikoog is expected to result in significant delays in connecting offshore wind to

[89] https://www.iucn.nl/en/project/bottom-line-a-fair-and-successful-energy-transition/
[90] https://www.government.nl/topics/nature-and-biodiversity/natura-2000
[91] https://www.noordzee.nl/marine-protected-areas-in-the-dutch-north-sea/
[92] https://qsr.waddensea-worldheritage.org/index.php/reports/introduction

onshore electrolysis. The Waddenzee Association is highly critical of the formal allocation of the planned new wind zones, which are crucial for scaling up green hydrogen production. The association wants to have a thorough understanding of the effects on marine flora and fauna before proceeding. Greenpeace Netherlands is less involved in such local and regional battles, but Faisa Ouhlasen, International Director of Energy Transition, supports hydrogen, as long as it is explicitly green.[93] Some shared characteristics can still be observed among these NGOs (Diagram 3): They all support a rapid and massive transition from fossil to sustainable energy; express enthusiasm for green hydrogen**;** want the greening through hydrogen to happen quickly, yet exhibit reservation when it comes to their own involvement and decision-making power; are reluctant towards partnering with large (fossil-dominated) energy companies such as Shell or RWE; understand the importance of solar and wind energy, but are concerned about the perceived negative effects on flora and fauna; are pressured by their own members, who often prioritise nature conservation without compromises, while the NGOs themselves are aware of the importance of accelerated energy transitions.[94]

Stakeholder Diagram 3 — Non-Governmental Organisation

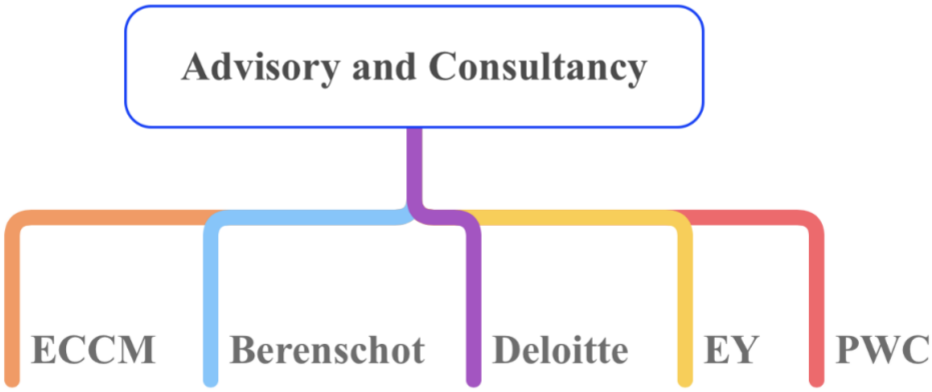


[93] https://www.power-technology.com/news/dutch-power-consortium-green-hydrogen-renewables/
[94] https://www.dnv.com/news/dutch-industrial-decarbonization-policy-effectively-supports-ccs-but-needs-further-push-on-low-carbon-and-green-hydrogen-to-meet-climate-targets-229507

Consultancies and Research & Development Institutions

The Netherlands has a range of excellent technical and research universities, in addition to numerous private research institutions. Both segments actively collaborate with the government and private sector, although universities are wary of undue influence from these external parties. In addition to existing research and development institutions specialising in environmental, climate, and energy themes, we are increasingly seeing major international consultancies such as Deloitte, PWC, and EY entering this market. It is not surprising that governments, businesses, and NGOs frequently rely on such research and development organisations. However, it is worth noting that most of the studies conducted in this research exhibit a positive outlook on hydrogen and offer little criticism of a starting period that includes blue hydrogen production.

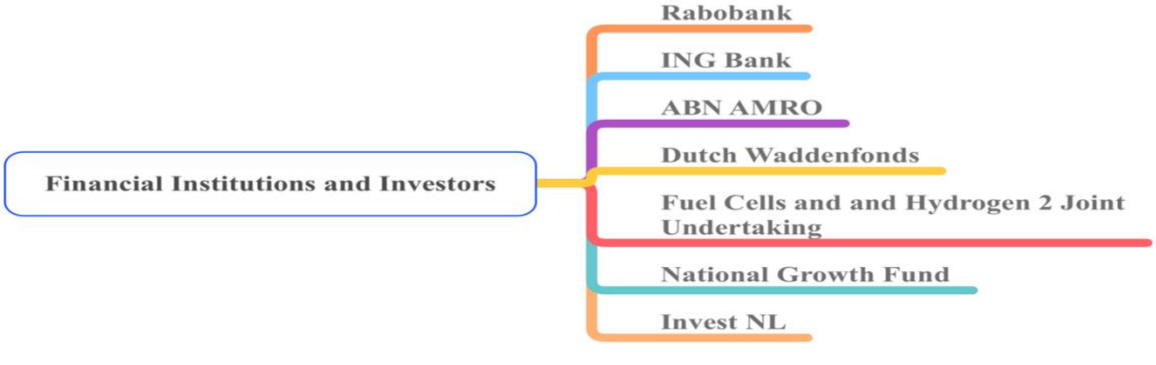
Stakeholder Diagram 4 — Advisory and Consultancy



Financial Institutions and Investors

The hydrogen market has attracted significant attention from the finance sector. However, it is notable that many financial institutions struggle with the uncertainties associated with new products in emerging markets, such as electrolysis or hydrogen exploitation. For instance, the construction and operation of large-scale (especially offshore) electrolysers are still unproven in extensive market applications.[95] Additionally, the ultimate effects on nature remain unknown, raising questions about the government's unwavering support for hydrogen. As a result, ensuring large-scale hydrogen projects is challenging, and they have complex return characteristics. This is one reason why only major energy players with substantial equity can engage in GW-scale hydrogen projects. The Dutch government has established its own investment vehicle, Invest NL, with a mandate to invest in such complex market domains that demonstrate future potential and serve a societal interest. Hydrogen is one of the new focal points for Invest NL. Financial institutions and investor (Diagram 5) belief in future opportunities and a willingness to invest, but typically with private or public co-financiers sharing part of the risk; have a strong reliance on governments for subsidies, more flexible regulations, and active government support for green companies, as well as stricter penalties for polluting companies; apprehension regarding political volatility, which often conflicts with the decades-long return periods involved; are hesitant to invest in cross-country partnerships such as the German Dutch-Norwegian NorthH2 project, as these collaborations are more challenging to predict, and control, compared to individual companies and national regulatory frameworks.

Stakeholder Diagram 5 — Financial Institutions and Investors

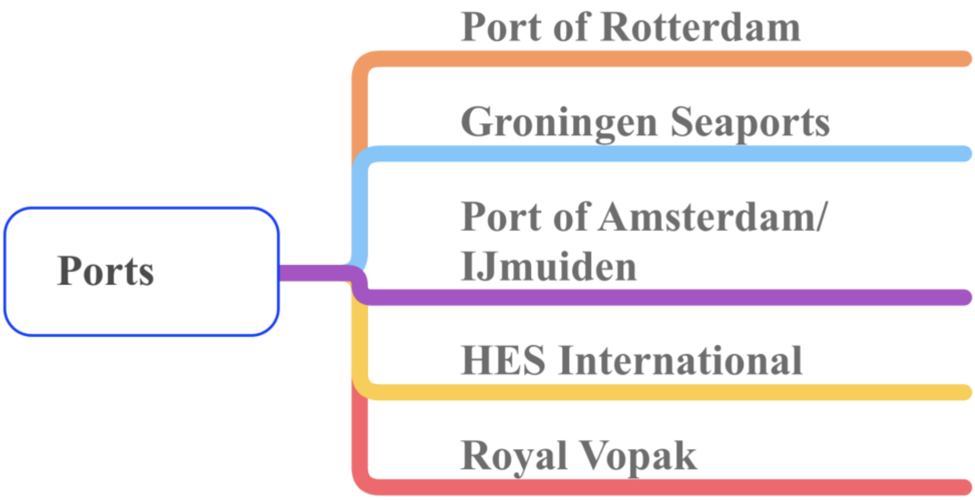


[95] https://www.industryandenergy.eu/hydrogen/shell-makes-final-investment-decision-for-holland-hydrogen-i/

Ports

From a Dutch hydrogen perspective, three seaports are most relevant: Rotterdam, Amsterdam and Groningen Seaports (Diagram 6). All three ports are currently active as hydrogen ports. The parallels between these ports are that they have governments as dominant stakeholders; want to sell land around the port for the construction of electrolysers; want to handle hydrogen in both liquid and gaseous form; and serve as a good steppingstone to reach the industrial clusters (major consumers) located nearby.

Stakeholder Diagram 6 — Port Authorities

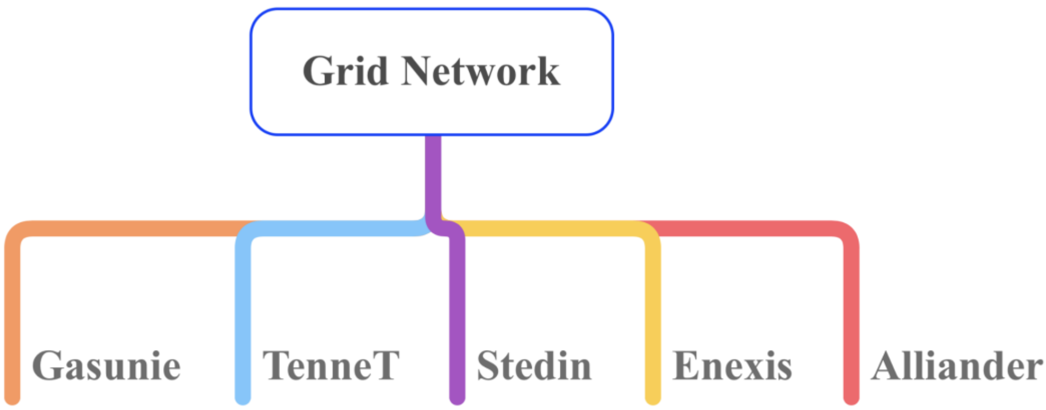


However, there are also significant differences. Rotterdam leads in terms of liquid gas storage. It will also play a key role in the transport of imported hydrogen to the Chemelot industrial area in South Limburg. On the other hand, Groningen Seaports has more space for large-scale electrolysis near the landing point of some of the largest offshore wind locations. Additionally, important natural hydrogen gas storage facilities are located around Groningen Seaports. Furthermore, this port enjoys a certain social-political advantage since the northern region is currently experiencing the most negative impacts of natural gas extraction. Both national and regional governments aim to boost the green energy position of the Northern Netherlands, with hydrogen as a key component. Amsterdam is currently a significant port, primarily for fossil energy carriers such as coal and oil. This port is under great pressure from the local government to transform into a sustainable port activity.

Grid Networks

The Netherlands has two major network companies: TenneT, responsible for large-scale electricity transmission, and Gasunie, responsible for large-scale gas transportation (Diagram 7). Regionally and locally, this function is taken over by regional network companies (Stedin, Enexis, and Alliander). Gasunie and TenneT are Transmission System Operators responsible for implementing Dutch energy policies (determined by the Ministry of MEAC) but are regulated by the Ministry of Finance. Despite their different activities and interests, Gasunie and TenneT collaborate well, resulting in annual joint studies on the energy transition, particularly IE2030 and Outlook 2050.[96] [97] Both TenneT and Gasunie have established a presence in Germany, thereby covering part of the German supply area. Gasunie has also connected to the United Kingdom through the subsea gas pipeline 'BBL'. This "expansion drive" was initially driven by the Dutch ambition to establish a European energy hub.

Stakeholder Diagram 7 — Grid Network



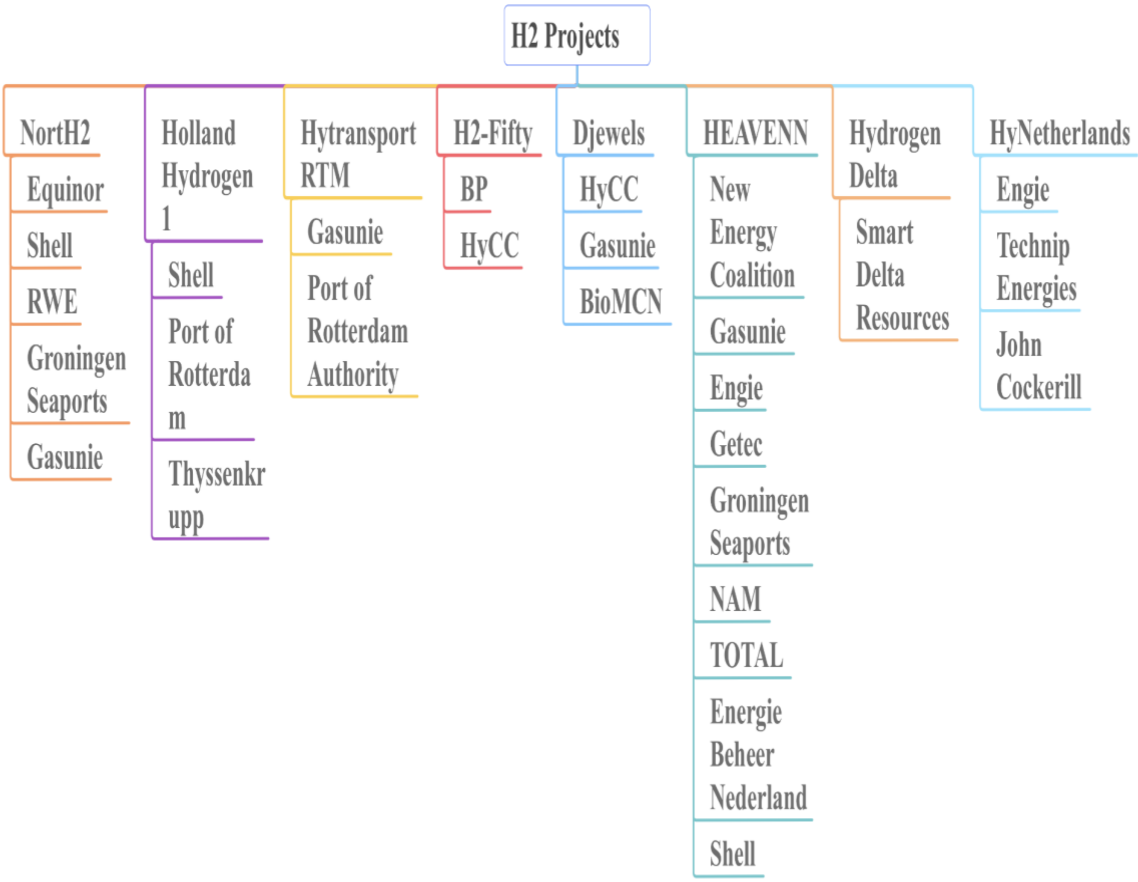
[96] https://www.gasunie.nl/en/expertise/energy-system/infrastructure-outlook-2050
[97] https://www.gasunie.de/en/news/gasunie-and-tennet-climate-goals-can-only-be-achieved-with-an-integrated-european-energy-system

H2 Projects

Almost all major hydrogen projects, especially those at GW scale, are collaborative efforts involving internationally operating energy companies such as Shell, RWE, Equinor, Eneco, Vattenfall, and Ørsted. The aforementioned network companies play a significant role in the distribution of these projects, with Gasunie, in particular, making its network fully capable of transporting hydrogen gas and being closely involved in all these projects. In 2019, this even led to Gasunie formally participating in the ambitious NortH2 project, which was initiated by Gasunie and Shell, and later joined by Equinor and Eneco. NortH2 aims to harvest large-scale wind energy in the North Sea and convert it into green hydrogen through electrolysers near the Eemshaven. The hydrogen can then be injected into Gasunie's natural gas network or stored in the natural storage facilities managed by Gasunie in depleted gas and salt fields. However, after intense political deliberations in the Dutch parliament and media discussions (the TV program Nieuwsuur on 21st of October 2021), Gasunie had to withdraw from the project because the company is not allowed to participate in commercially profit-oriented projects.[98] For larger hydrogen projects (Diagram 8), they are collaborative projects involving multiple (energy) companies; aim for a comprehensive approach, encompassing production, storage, distribution, and (future) sales; seek both national and European subsidies; require political support to cover initial losses until market-ready operation; compete for the best electrolyser locations, preferably near ports and face resistance from those who prioritise using scarce green electricity directly rather than converting it into hydrogen at an energy loss.

[98] https://www.gasunie.nl/en/news/gasunie-asks-for-more-clarity-on-hydrogen-cooperation

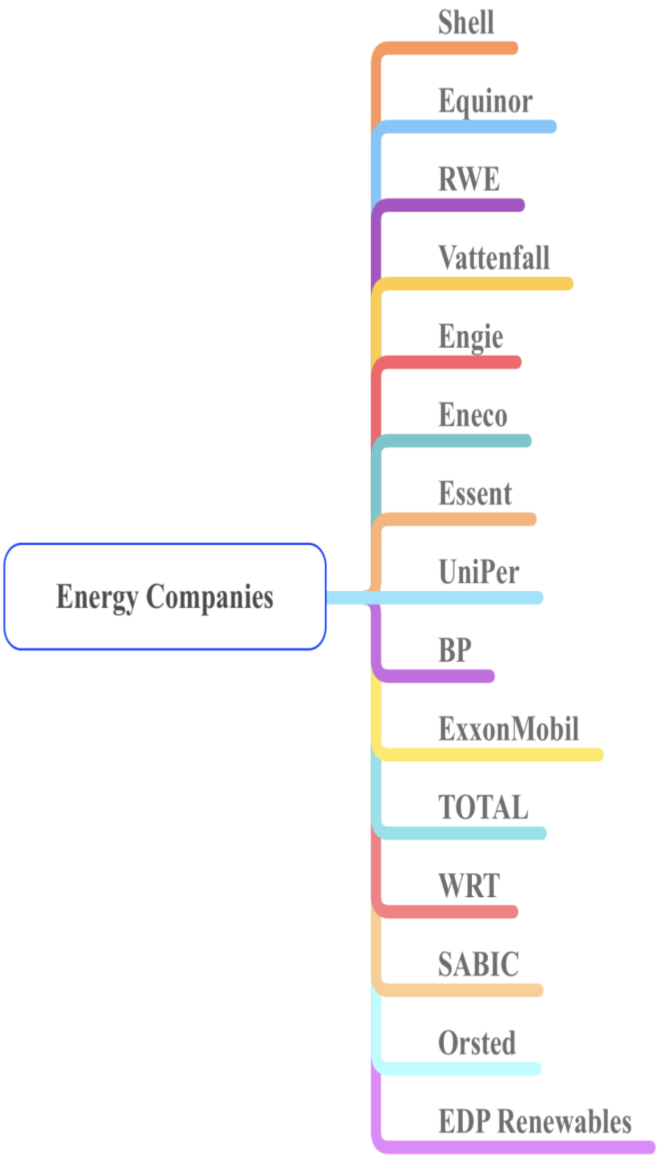
Stakeholder Diagram 8 — Hydrogen Projects (H2 Projects)



Energy Companies

The field of energy companies operating in the Netherlands is diverse (Diagram 9). Fully private energy companies like Shell operate in the same commercial playing field as wholly or partially state-owned companies like Engie. However, for the hydrogen transition, this incongruence between private and public companies seems to have little significance. In the Netherlands, Shell Nederland is by far the largest player and investor in hydrogen, but RWE, Engie, Ørsted, and Eneco are also increasingly making their presence felt in the construction of (particularly offshore) wind farms for hydrogen production. From a hydrogen perspective, the following applies to the aforementioned energy companies active in the Dutch hydrogen market: all have strategically chosen a gradual transition from fossil to green molecules; see this transition as ultimately maintaining their current role as producers, processors, and sellers of energy molecules; have critical shareholders who view excessive and premature investments in green molecules as detrimental to the current business model; face growing daily resistance (e.g. Extinction Rebellion) against the fossil fuel-based business model; engage, to varying degrees, in greenwashing (the act of making a policy, product or activity seem more environmentally friendly than it really is) by giving more visibility to relatively small investments in green energy forms like hydrogen, compared to their continued fossil fuel activities.[99]

Stakeholder Diagram 9 — Energy Companies

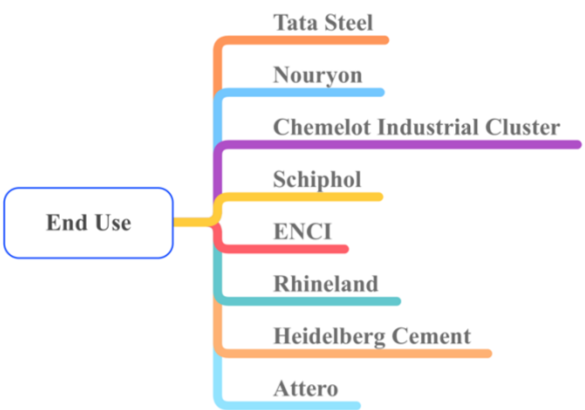


[99] https://www.theguardian.com/environment/2022/feb/16/oil-firms-climate-claims-are-greenwashing-study-concludes

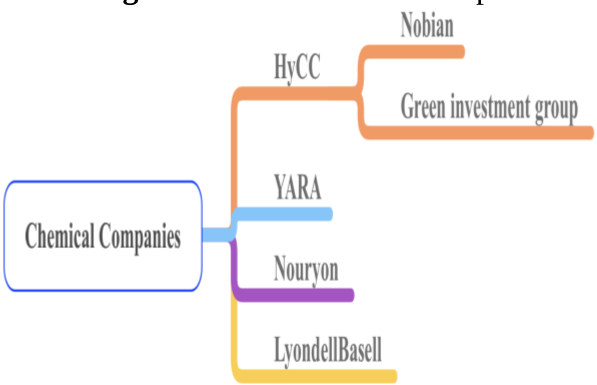
Industrial End Users

This brings us to the end users (Diagram 10-12). In the energy transition goals for 2030 and 2050, the emphasis is on industrial end users, particularly the hard-to-abate companies for whom a complete transition from fossil molecules to green electrons is not feasible. We can roughly categorise them as follows: a) Companies like Tata Steel (Diagram 10), which require molecules for the high temperatures of the steel production process and b) Companies like Yara (Diagram 11), which need hydrogen as a raw material and feedstock for fertiliser production. If the Netherlands could successfully convert these hard-to-abate industries from fossil to green molecules, it could reduce the fossil footprint of the Netherlands. Regarding these major consumers, the following observations can be made: All of them increasingly feel the pricing pressure on emissions (ETS) impacting their operations; experience a decline in their societal license to operate as long as they maintain a dominant fossil profile.

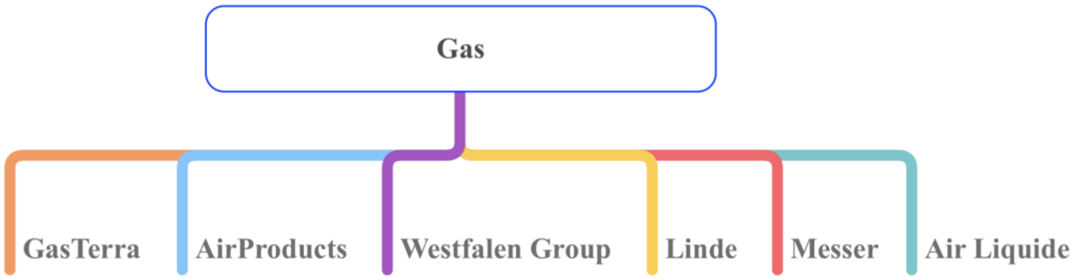
Stakeholder Diagram 10 — End Use



Stakeholder Diagram 11 — Chemical Companies



Stakeholder Diagram 12 — Gas



Furthermore, it can be said that: All of them recognise that greening their own products (such as green steel) can eventually provide a competitive market advantage; acknowledge that the EU's aim to impose heavier fiscal burdens including CO2 taxes on products outside the EU make their own investment in greening more financially viable: are extensively engaged in discussions with GW-scale hydrogen projects such as AquaVentus in Germany and NortH2 in the Netherlands; seek guarantees regarding price and security of supply before committing to the transition.

This chapter has examined where the most significant accelerators for the Dutch hydrogen supply chain lie, such as the offshore wind potential, the maritime connectivity, the storage potential of hydrogen in the Netherlands and the trade with North-Western European countries including Germany, that strengthen the Dutch hydrogen hub in the North Sea. This chapter has further attempted to delineate the major stakeholders, projects and ambitions in the Dutch hydrogen landscape. The next chapter deals with the major shortcomings of the supply chain seeking to analyse where the most significant obstacles for the Dutch hydrogen can be found.

Chapter 3: Overcoming Obstacles: Charting the Course

Blue hydrogen, and green hydrogen have gained significant attention as front runners in the new energy landscape. These forms of hydrogen are the focal point of ambitious decarbonisation targets in the Netherlands. However, the path towards sustainable hydrogen economies is riddled with complexity and obstacles. As Notteboom argues: "The transition to hydrogen is not merely a fuel replacement, but a shift to a new system with political, technical, environmental and economic disruptions."[100] This chapter aims to examine these disruptions and bottlenecks.

General Risks and Implications for the National Hydrogen Supply Chain

Besides the most leveraged argument against green hydrogen, its inefficiency, there are other country-specific risks pertaining to the low-carbon and renewable hydrogen supply chains that warrant further analysis. The Dutch government identifies challenges, including a shortage of green hydrogen production capacity, that could impede the potential for hydrogen decarbonisation. Moreover, the government acknowledges uncertainty regarding the market development of hydrogen carriers. Lastly, the Dutch governments questions the realism of the expected volumes of hydrogen available for trade in the Netherlands, and whether these targets are not set too high.[101]

Building upon the challenges of green hydrogen shortages, market uncertainty and carrier related-concerns, additional factors contribute to bottlenecks in the Dutch hydrogen supply chain. These encompass, the entrenchment of fossil-based hydrogen and CCS, import impediments, sustainability performance standards, the multifaceted-use cases of hydrogen, supply chain resilience for electrolysers, and the impact of the ETS. An interviewee from a Dutch Port summarises the uncertainty pertaining to the hydrogen supply chains present in the Netherlands: "The business case in the Netherlands is potentially great. But if it would be really that excellent, then everything would be in its implementation phase. Currently, there is no business case for hydrogen that is completely conclusive."[102]

[100] Notteboom, Theo(2023): p.2.
[101] Rapport studie omgevingsveiligheid toekomstige stromen waterstofrijke energiedragers - Ministerie van Infrastructuur en Waterstaat 17 Maart 2023
p.3.
[102] Appendix A – Interview 6 "C-Level representative of a Dutch Port Authority"

Although the Dutch infrastructure is an accelerator for the hydrogen supply chains of the Netherlands, the cost of retrofitting the Dutch infrastructure would cost an estimated €1.5 billion. Around 85% of the the hydrogen infrastructure could be realised through the retrofitting of the existing Dutch natural gas infrastructure. But in reality, as an interviewee from an infrastructure and transportation company pointed out, the costs might be higher, especially if the higher costs for steel are taken into account. Moreover, due to the plans to create a North-West European hydrogen hub, additional costs have to be factored such as the cost for interconnections between countries. Important debates have to take place between partner countries with regard to who pays what. With regard to the trade with Germany, the interviewee points out that much depends on the speed with which the Dutch hydrogen infrastructure is going to be developed, lest Germany finds alternative suppliers.[103] An interview with a hydrogen valley expert underscores that Russia's invasion of Ukraine has shifted the Dutch government's plans for retrofitting natural gas pipelines that were imagined for hydrogen transportation. It is this expert's contention that it could mean that these pipelines will not become available as they will remain saturated by natural gas. [104]
That could be an inhibitor for the hydrogen backbone in the Netherlands.

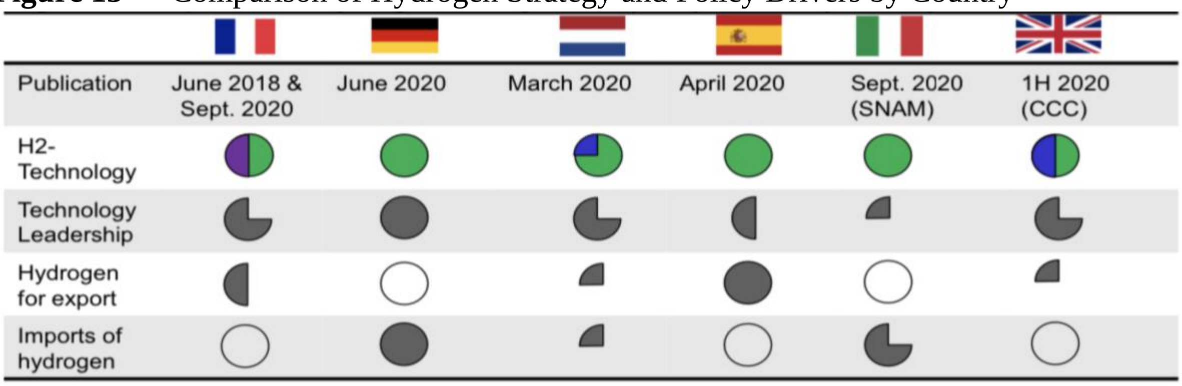
The Limits of Imports and the Impact of Environmental, Social and Governance (ESG) Requirements on Hydrogen

The Dutch MoU's with various nations for the extensive import of green hydrogen — the molecule that has the lowest life-cycle emissions and likely the lowest long-term mitigation costs — have been highlighted in Chapter 2.[105] Although these MoU's are paving the way for an increased hydrogen trade, in the words of a policy advisor interviewed, this is not saying anything as long as there are no volumes coming to the Netherlands. It only gives an indication of which partners are selected for future cooperation, among those the port of Sohar, of which Rotterdam has a 50% stake and seems to have the best cards for short-term imports to the Netherlands. Another obstacle would be that the majority of the potential hydrogen exporting nations are also big oil states that have significant hydrocarbon interests. Why should these countries produce their maximum volumes of hydrogen if that hurts their main industrial model?[106] Questions pertaining import also touch transport via ships. If this

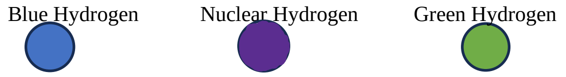
[103] Appendix A – Interview 3 "Representative from an infrastructure and transportation company"
[104] Appendix A – Interview 15 "Hydrogen valley expert"
[105] Odenweller, Adrian, et al. "Probabilistic feasibility space of scaling up green hydrogen supply." (2022) p.854.
[106] Appendix A – Interview 9 "Policy Advisor for a Dutch energy consultancy"

will be the main mode of hydrogen transportation, what fuels would these ships run on? Will they run on hydrogen or on fossil fuels? These issues are of yet largely unsolved.[107]
These restrictions for hydrogen imports constitute a barrier for the Netherlands. It is estimated that the import targets for hydrogen within the EU are overly ambitious.[108] Gunnar Luderer of Potsdam Institute has stated that it is “highly uncertain when the hydrogen volumes that politicians are planning will actually be available” and “whether hydrogen imports can make a significant contribution to covering demand as early as 2030 is not foreseeable at the moment. Import trends are the great unknown in the hydrogen ramp-up.” [109] But there are also ESG requirements that will increasingly play a role in the hydrogen sector as governments and societies are increasingly pressing for climate mitigation, addressing social inequality and to hold companies accountable for excessive water usage in. The government of Germany does not want green hydrogen projects to come at expense of local environments by burdening the water supply of hydrogen producing countries.[110] Another inhibitor for the Dutch and EU hydrogen supply chains with regard to ESG requirements and hydrogen imports from countries like Tunisia and Morocco, could be questions pertaining to the fairness of potential revenue streams of the international hydrogen trade.[111] Figure 13 highlights the different perspectives of hydrogen production in different countries.

Figure 13 — Comparison of Hydrogen Strategy and Policy Drivers by Country



Source: Oxford institute for Energy Studies (2021) p.2.



[107] Ibid. – Interview 13 “Hydrogen Technology Specialist”
[108] Odenweller, Adrian, et al. (2022) p.858.
[109] https://www.cleanenergywire.org/news/germany-might-not-have-enough-hydrogen-government-plans-researchers
[110] https://www.cleanenergywire.org/news/germany-says-green-hydrogen-imports-should-not-harm-environment-partner-countries
[111] Appendix A – Interview 13 “H2 Technology specialist”

The Dichotomy Between Blue and Green Hydrogen

One inhibitor for the green hydrogen case in the Netherlands is its cost aspect, which is currently significantly higher than that of blue hydrogen. Although the cost of renewable energy and electrolysers is expected to decrease, it is unlikely that a sufficient amount of green hydrogen will be available in society for the upcoming decades.[112] Blue hydrogen, being more competitive and developed, is seen as a potential intermediary option. According to a policy advisor for the Dutch government, blue hydrogen could be a long-term solution for the Netherlands, considering the storage facilities in the country. In this interview, the cost of green hydrogen among different member states was stressed, the Dutch prices for green hydrogen would never be able to compete with countries closer to the equator. Another vital point to consider is that green and blue hydrogen can be considered competitors. The companies that develop CCS projects, which have a lifetime of around 10-15 years would be threatened by the EU's targets of using 42% of green hydrogen in industry by 2030. It would be difficult to make a return on investments for such CCS projects.[113] This argument highlights the tensions that exist between the stringent EU's green hydrogen targets and the cost-competitiveness of blue hydrogen, which on the short-term is the better solution, but would become less attractive in the long-term.

The Dutch government perspective on blue hydrogen and CCS is mixed. One the one hand, it is considered a necessary low-carbon technology for energy transitions.[114] On the other hand, Dutch Climate and Energy Minister, Rob Jetten argues against additional hydrogen production from natural gas, emphasising the importance of stimulating cost-effective renewable hydrogen. The Minister views binding targets for renewable hydrogen use in industry and transportation as an efficient option that maintains a level-playing field in Europe.[115] The Ministry also acknowledges the role of low-CO2 in contributing to the 2030 decarbonisation goals: "If the production of renewable sources of hydrogen develop more slowly than expected, and if alternative natural gas suppliers are to be found, then hydrogen production from natural gas can be ascribed a greater role if it results into cost-effective CO2

[112] Howarth, Robert W., and Mark Z. Jacobson. "How green is blue hydrogen?" (2021) p.1677.
[113] Appendix A – Interview 5 "Policy Advisor for Dutch government"
[114] Questions asked by members of the House, with answers given thereon by the government (2021-2022) https://www.tweedekamer.nl/downloads/document?id=2022D34378
[115] New Commission proposals and initiatives from European Union member states (2021-2022) https://www.tweedekamer.nl/downloads/document?id=db1f61db-a65f-4e28-9ae9-4a885c3fa0ed&title=Reactie%20op%20artikel%20Follow%20The%20Money%20over%20Europese%20waterstofambities.docx

reduction."[116] In light of the views presented by the Dutch Climate Minister, it is evident that the Dutch government perspective seeks a pragmatic balance between the necessity of low carbon technologies such as blue hydrogen and decarbonisation efforts. A policy advisor for the Dutch government acknowledges that although natural gas prices remain high in the EU on the short-term, the long-term expectation is that the prices for natural gas will drop, which could result in blue hydrogen becoming the better option for the Netherlands. According to this interviewee, increased carbon prices under the ETS will only result in CCS projects becoming more effective.[117]

However, as highlighted by Thijs de Graaf, blue hydrogen might continue to dominate the supply picture, potentially conflicting with mid-century net-zero targets.[118] While countries like Germany and the Netherlands acknowledge this risk and aspire to swiftly transition to green hydrogen, the likelihood of immediate adoption in the short term remains low.[119] [120] Nevertheless, for hydrogen value-chains around the EU, with the exception of the Southern EU member states, blue hydrogen is expected to serve as the short-term option.[121]

Are the Dutch Locking in on Blue Hydrogen with CCS?

But what are the effects of blue hydrogen on the Dutch efforts towards achieving its decarbonisation objectives? Jan Rosenow, an energy policy expert, argues against the viability of blue hydrogen as a means to achieve energy independence, a newfound priority for the EU following the Russo-Ukraine conflict. Emphasising the risk of lock-in, Rosenow highlights the significant susceptibility to price fluctuations in fossil fuels. Furthermore, considering the diminishing gas production, coupled with the estimated energy losses of up to 40% associated with the production of blue hydrogen from fossil gas, the drawbacks, in Rosenow opinion, have become even more pronounced.[122]

But not all experts agree that blue hydrogen is a bottleneck for the Dutch hydrogen supply chain. Some experts, like Barthold Schroot, an energy expert in sustainable energy sources,

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116 Letter from the minister for Climate and Energy - To the Speaker of the Lower House of the States General The Hague, June 10, (2022) https://www.tweedekamer.nl/downloads/document?id=db1f61db-a65f-4e28-9ae9-4a885c3fa0ed&title=Reactie%20op%20artikel%20Follow%20The%20Money%20over%20Europese%20waterstofambities.
117 Appendix A – Interview 5 "Policy Advisor for the Dutch Government"
118 Van de Graaf, Thijs. (2020) p.33.
119 Ibid. p.33.
120 Report study environmental safety future flows of hydrogen-rich energy carriers - Ministry of Infrastructure and Public Works (2023) https://open.overheid.nl/documenten/ronl-4faea8d348072a617cef10e91c086730492404fc/pdf
121 https://www.euractiv.com/section/energy/opinion/europes-hydrogen-split-blue-vs-green-and-north-vs-south/
122 Lowes, Richard, and Jan Rosenow. "How much would hydrogen for heating cost in the UK?." (2023) p.1.

considers the use of blue hydrogen a vital transition fuel for the Dutch energy system. As the Netherlands would require some 3.5 Mt of hydrogen by 2050, Schroot argues that these volumes of hydrogen could only be supplied through three methods: imports, domestic production of green hydrogen and domestic production of blue hydrogen.[123] As blue hydrogen is 2-3 times cheaper then green hydrogen and can be scaled up faster, it makes for a viable transition fuel. Considering the limitations on the import dimension of Dutch hydrogen supply chains and the insufficient renewable production to achieve the volumes of green hydrogen production in the Netherlands, it seems that blue hydrogen is here to stay. A carbon lock-in specialist interviewed about the potential threats with regard to CCS argues that it is not necessarily a black and white picture. This interviewee highlights the role of CCS for meeting climate goals. CCS would become a risk if it is not regulated. Only when fossil fuel-based industries are doubling down on CCS as a way of perpetuating their business models, then it becomes a source of significant problems, but as an intermediate step it can be considered helpful. Furthermore, the expert expresses that deep decarbonisation is impossible without the use of CCS. [124] The Dutch government should therefore regulate CCS and to ensure that unnecessary usage of CCS is discouraged.

Carbon Lock-in

It is important to address challenges posed by the potential carbon lock-in that the blue hydrogen molecule could present for the Netherlands. Indeed, as Rosenow mentioned, the concept of lock-in is important for fully addressing this issue. Carbon lock-in, a concept first coined by Gregory Unruh, in his 1999 doctoral thesis titled “Escaping Carbon Lock-in”, can be even more useful to, in the words of Unruh: “illuminate self-reinforcing barriers to change created by techno-institutional complexes that inhibit policy action even in the face of known global climate risk and the presence of at least cost-neutral, if not cost effective, technological alternatives.”[125] While green hydrogen technologies, on the short-term does neither provide a cost-neutral nor a cost-effective alternative, it could become a cost-competitive technology in the mid to long-term with improvements of electrolyser technology, economies of scale and the decreasing cost of renewable energy. Regardless, Unruh’s carbon-lock in framework guides our understanding of what the dangers are of not adequately stressing blue hydrogen’s intermediate role as a transition fuel, and to not allow blue hydrogen to become a replacement

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[123] https://energypost.eu/the-netherlands-a-blue-hydrogen-economy-now-will-ease-a-transition-to-green/
[124] Appendix A – Interview 7 “Carbon lock-in Specialist”
[125] Unruh, Gregory C. "Escaping carbon lock-in." (2002) p.317.

for efforts to support or subsidise green hydrogen. The carbon lock-in specialist interviewed on this topic argues that anything that can kind of delay or prohibit the system to shift from polluting fossil-based industry can be categorised as a source of carbon lock-in.[126] Blue hydrogen can therefore be considered a potential inhibiting factor for the rollout of the Dutch green hydrogen supply chain. As addressing grand challenges, like climate challenge, require a significant overhaul of societies, industries and consumption patterns, it is of the essence that policy makers, industries and societies at large take proactive steps to mitigate these carbon-lock in climate risks.[127] While blue hydrogen can be said to be a steppingstone on the path towards green hydrogen, it should not distract from the gargantuan challenge of phasing out fossil fuels.

There risks are acknowledged by scholars who emphasise that a technology like blue hydrogen can effectively prolong the lifespan of hydrocarbons such as natural gas. Thijs de Graaf mentions that such risks are especially significant when other technologies like heat-pump rollout or direct electrification would suffer as a result.[128] The significant investments for blue hydrogen should also not be underestimated, as blue hydrogen is still more expensive than using natural gas.[129] A C-level representative of a Dutch Port Authority, when questioned with regard to the potential carbon lock-in effects of blue hydrogen, argues for an approach in which blue hydrogen is necessary to bridge the gap in the Netherlands. “Stimulate green hydrogen, tolerate blue hydrogen and discourage grey hydrogen. Blue hydrogen will have a place in our energy systems for 10-15 years and is a transition fuel. That is the time that we need to develop green hydrogen fully.”[130]

[126] Appendix A – Interview 7 “Carbon lock-in specialist”
[127] van der Loos, HZ Adriaan, Simona O. Negro, and Marko P. Hekkert. "Low-carbon lock-in? Exploring transformative innovation policy and offshore wind energy pathways in the Netherlands." (2020) p.1.
[128] Van de Graaf, Thijs. (2020) p.33.
[129] Appendix A – Interview 2 “Representative of an international energy company working for a H2 project”
[130] Ibid. A – Interview 6 “C-level representative of a Dutch Port Authority”

Stranded Assets for CCS technologies and Storage Issues

In the case of the Netherlands, a significant obstacle of direct electrification for most sectors would lead to stranded assets (assets that no longer earn an economic return), which may reduce political and industrial support, and this is not in the best interest of most stakeholders.[131] Most companies also perceive hydrogen as a business opportunity that uses rather than strands fossil fuel infrastructure.[132] Therefore, in the context of the Dutch hydrogen landscape, these aspects have to be taken into consideration to strike the right balance between climate mitigation efforts and economic feasibility. The same is true for new investments in CCS technologies, which would be a sensible short-term solution, yet the business case for CCS will diminish over time as societies progressively reduce their reliance on fossil fuels. An interview with a carbon-lock in specialist highlights that investing in CCS installations add sunken costs to the system. When the need for the production of green hydrogen increases, you risk that these CCS assets become stranded, as there is no use for CCS in green hydrogen production.[133] Policy makers should ensure that investments in CCS do not become an excuse for a prolongation of fossil fuel use in the Netherlands.

With regard to the storage of hydrogen many problems persist that need to be addressed. A hydrogen chemistry expert interviewed on this issue argues that due to the low energy density of hydrogen, the current Dutch HyStock cavern is only capable of storing a base load for a 500 MW electrolyser. The interviewee argues that considering the pending 10 GW target of green hydrogen production by around 2027, the Netherlands would need 20 such projects to store all the hydrogen. Such storage capacity would be vital considering the fact that the green hydrogen for the Dutch industry should be base-load available.[134] Such scale-ups might not be feasible considering the current proven storage capacity of 500 MW. The feasibility issues of scaling-up the necessary storage could prevent the Netherlands from leading in the hydrogen landscape.

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131 Åhman, Max, Lars J. Nilsson, and Bengt Johansson. "Global climate policy and deep decarbonization of energy-intensive industries." (2017)
132 Mercure, J.-F. et al. “Macroeconomic impact of stranded fossil fuel assets”. (2018)
133 Appendix A – Interview 7 “Carbon-lock in specialist”
134 Appendix A – Interview 14 “Hydrogen Chemistry Specialist”

Infrastructural Lock-in

The Netherlands faces the risk of technological and infrastructural lock-in, particularly concerning the development of the Delta Rhine Corridor. A key concern is whether it is prudent to invest in ammonia infrastructure, potentially locking the country into one carrier technology, while alternative options like liquified hydrogen may yet emerge as the most cost-competitive.[135] While ammonia currently offers favourable cost and volume advantages, the soundness of investing in its supportive infrastructure raises questions. Factors to consider for the Netherlands include determining the demand, volume and preferred carrier. With these questions only partially answered, there are risks of lock-in with selecting the carrier for the future and deciding whether to invest in its supporting infrastructure now and potentially face lock-in later.[136] An interviewee from an infrastructure and transportation company points out that those questions remain open-ended. If the Dutch double down on ammonia, questions like whether it should be cracked on site and then transported to the end user, or whether it should be transported directly via pipelines should be answered on the short-term. Other questions pertain to the safety aspects of ammonia, with some municipalities stating that they do not want the transportation of ammonia on their territory. Furthermore, the interviewee raised the point to what extent the natural gas infrastructure of the Netherlands would still be a viable accelerator, as ammonia would need new dedicated infrastructure.[137] Ammonia could therefore undermine the accelerator of retrofitting current natural gas infrastructure. A policy advisor working for the Dutch government argues that the current safety regulations were not designed for these massive imports of ammonia. This experts confirms that municipalities could revolt if massive volumes of ammonia would be imported via rail through their areas. This could additionally have complications for the wider acceptation of hydrogen.[138]

In the same vein, industrial lock-in poses a significant risk, particularly concerning the Dutch Chemical Industry (DCI), which encompasses the petrochemical sector. The DCI is among the country's most GHG-intensive industries, accounting for 16% of direct CO2 emissions and around 7% of total GHG emissions. In 2015, the DCI accounted for 8% (18MtCO2) of the nation's total GHG emissions. The changes necessary in the sector will require 'industrial

[135] TNO - Environmental safety of future flows of hydrogen-rich energy carriers - Public - (2023) p.9.
[136] Ibid. p.25.
[137] Appendix A – Interview 3 "Representative of a transportation and infrastructure company"
[138] Ibid. – Interview 5 "Policy Advisor for the Dutch Government"

system transition'.[139] The cost-competitiveness of green hydrogen and the issue of sufficient supply pose significant obstacles to such industrial system transition in the DCI. According to the VNCI, a chemical industry union, the most cost-effective pathway for decarbonising the industry through hydrogen is estimated to be approximately 50% higher than the business-as-usual (BAU) scenario, where fossil fuels remain competitive. [140] The high costs of hydrogen technologies add complexity to the equation, leading to contested discussions about subsidising industrial clusters to overcome cost barriers for green hydrogen technologies. It is in this context that the Dutch government faces a challenging task of striking the right balance between creating favourable conditions for decarbonisation and ensuring the competitiveness of its industries, especially considering the looming departure of certain manufacturers. It is crucial to balance decarbonisation targets achieved through the use of hydrogen, all the while considering the potential impact on the competitiveness of Dutch industry products in international markets, if the costs associated with the 42% green hydrogen target are borne by the hydrogen-consuming Dutch industry.[141]

Regulatory Obstacles

An obstacle for the Netherlands is a clear regulatory framework that allows for a conducive investment climate for low-carbon or clean hydrogen. Currently, it remains difficult for investors to take decisions as the regulatory and policy framework is not entirely clear. The HyDelta 2 study has done an extensive stakeholder mapping with regard to this issue and the results show that insecurities are present in the entire supply chain. Even-though the majority of the stakeholders in the Netherlands do acknowledge that the regulatory wheel is spinning, it is the consensus that this is often too slow. Temporary safety guidelines for ammonia transports are considered as the best and most flexible way forward as the hydrogen landscape is rapidly changing and regulation has a hard time keeping up.[142]

Additionally, regulatory clarity for uncontroversial hydrogen use cases should be implemented. A policy advisor for the Dutch government argues that it is not in the interest for the government to make policy with regard to the use of hydrogen in the steel sector, (a good use case for hydrogen) as the government aims to firstly decarbonise the grey hydrogen

[139] Janipour, Zahra, et al. "What are sources of carbon lock-in in energy-intensive industry? A case study into Dutch chemicals production." (2020): p.1-2.
[140] Janipour, Zahra. Socio-Technical Dynamics of the Transition to Net-Zero in the Chemical Industry. (2023) p.30.
[141] CE DELFT – TNO: "50% green hydrogen for Dutch industry" (2020) p.5.
[142] HyDelta 2 – Marit Sprenkeling - WP10 – Social acceptance for hydrogen transport and storage (2022)

use as a feedstock. There are no plans for using subsidies for hydrogen use in the steel sector, as this is considered a lesser priority. The policy advisor stresses the fact that the Dutch government cannot and should not subsidise the use of hydrogen in sectors that do not currently use the molecule, as it is impossible to predict what would be the most cost-competitive solution in these sectors.[143] Although the governments perspective on tackling the industries that already use the molecule in high-priority sectors, the Dutch hydrogen roadmap nonetheless foresees a role for hydrogen use in light-mobility, which is considered a controversial hydrogen use. According to one interviewee, hydrogen for steel and cement should be included as a top priority.[144]

Upstream and Midstream Hydrogen Supply Chain Issues: Offshore Wind Insecurities and Electrolyser Technology Readiness

Another obstacle for the Dutch hydrogen ambitions finds itself at the heart of the Dutch decarbonisation goals, the offshore wind industry, where the Netherlands is one of the most ambitious countries in Europe.[145] With the sevenfold increase of 21.5 GW towards 2030 that the Dutch government aims to achieve for offshore wind capacity, much of the success of this strategy depends on how the market for industrial electrification, gas and CO2 prices unfold. Much is indeed at stake, as the offshore wind capacity of the Netherlands is considered to be the primary contributor to a CO2-free Dutch system with an estimated supply of 45% and 58% of total electricity demand.[146] A recent study by TNO has indicated that increased market volatility can increase risks for the offshore wind business. The results from this study show that the risk for an unfeasible wind business by 2030, due to market dynamics related to excess supply exist (even when exports to third countries is taken into consideration).[147] A carbon-lock in specialist interviewed for this paper argues that the potential off-take of renewable wind electricity for green hydrogen production is threatened by the industry choosing the CCS and blue hydrogen supply chain route.[148] Another obstacle to critically examine, is whether the cooperation of the North-Western European nations in offshore and onshore energy production for alleviating intermittency problems can really be said to be a

[143] Appendix A – Interview 5 "Policy advisor for the Dutch Government"
[144] Ibid. – Interview 10 "Policy Advisor for an International Advisory Association"
[145] TNO – Iratxe Gonzalez-Aparicio "Offshore wind business feasibility in a flexible and electrified Dutch energy market by 2030" (2022) p.4.
[146] Ibid. p.4.
[147] Ibid p.3 .
[148] Appendix A – Interview 7 "Carbon Lock-in Specialist"

short-term accelerator, as the offshore wind inter connectors between North Sea countries remain highly speculative and are not close to their implementation phase.[149]
With regard to the midstream of hydrogen supply-chains, one interviewee addressed the obstacles for electrolyser rollout necessary for the production of green hydrogen. Although many stakeholders engage in the building of electrolysers, these technologies are very new and sometimes Dutch policy makers seem to underestimate the technological readiness with regard to this technology. The interviewee argues that the technology is not mature yet and electrolysers are not in their "plug and play" phase yet.[150]

EU Regulation and Green Hydrogen

A policy advisor from an international advisory organisation argues that, due to the EU policies like the RED II, the REPowerEU and the delegated acts on the RFNBO's, blue hydrogen and natural gas are simply not going to cut it. In the words of this interviewee, the policies of the EU focus on the production of green hydrogen, which is reflected in the policies mentioned. But the interview also stresses that the EU policies are overly ambitious and not attainable when it comes to the supply-chain implementation for hydrogen. For the EU's domestic hydrogen production target of 10 Mt by 2030, the current EU electrolyser capacity sits at 160 MW and would need to be scaled up to 6000MW by 2025. Another obstacle mentioned that inhibits the success of the EU hydrogen supply-chain are the amendments proposed under RED II that require 5,7% of all transport to use RFNBO's (where it currently sits at 1%). When this target becomes mandated it could go against what the market says about the price of hydrogen.[151]

Another example mentioned by a policy advisor for the Dutch government is the EU regulation on additionality, which requires dedicated renewable electricity generation for the production of hydrogen. This EU regulation has the consequence that these additional renewable energy production sites necessary for the production of green hydrogen cannot flow to alternative applications necessary for the Dutch decarbonisation goals and could still cannibalise green electricity from the electricity grid. In turn this could have wider implications for alternative technologies like heat-pumps.[152]

[149] Ibid. – Interview 14 "Hydrogen Chemistry Specialist"
[150] Ibid. – Interview 14 "Hydrogen Chemistry Specialist"
[151] Ibid. – Interview 10 "Policy advisor from an international advisory organisation"
[152] Appendix A – Interview 5 "Policy Advisor for the Dutch Government"

Supply and Demand Issues:

The gargantuan task of decarbonising only the use of hydrogen as a feedstock is a good example of the supply and demand problems that exist within the current Dutch hydrogen landscape. In the Netherlands, it is the case that hydrogen use as a feedstock is mainly present in only a few stakeholders, those being YARA in Sluiskil and OCI in Chemelot and in Delfzijl with BIOMCN. These companies use the most hydrogen, with a 70% of total Dutch hydrogen use. If the Dutch government wants to meet the EU hydrogen target of 42% green hydrogen use in industry, it will only increase demand for the low-carbon molecule without increasing the supply of decarbonised hydrogen.[153]

Industry Flight and Competition Between Member States

The debate regarding the risk of industry flight, due to the high prices of natural gas as a direct consequence of the Russian invasion of Ukraine, has increased in the Netherlands. One of the reasons why many factories located to the Netherlands were the very comfortable prices for natural gas. The question thus becomes whether industries remain considering the high energy prices. Difficult discussions have to be had with regard to competitiveness in the EU and in the Netherlands. The war in Ukraine has highlighted problems with maintaining critical supply chains for vital goods and resources, which could be a reason to maintain these industries within the EU.[154]

An interview with a policy advisor, working for a Dutch energy consultancy, highlights that the Dutch government wants to maintain the five Dutch industrial clusters under the precondition that they meet the Dutch climate targets as presented in Chapter 1. Increasingly, however, as the interview shows, the sentiment grows within these clusters, that although decarbonisation is part of their strategies, it will not be for every price. The conversation is intensifying between the government and companies, and is of significance as the hydrogen demand in the Netherlands depends largely on whether industries choose to stay. The interview argues that whether the industry remains in the Netherlands has significant implications for the Dutch hydrogen chances.[155]

[153] Ibid.
[154] Ibid. – Interview 8 “Hydrogen specialist from a Dutch Technical University”
[155] Appendix A – interview 9 “Policy advisor working for a Dutch energy consultancy”

Another inhibitor for the Dutch hydrogen case is the competition with Southern European nations, which enjoy great renewable potential and are well positioned to benefit from the export of hydrogen originating from North African countries. Although Rotterdam has a great position in the EU, there is a significant chance that this advantage will be diminished by the great renewable potentials of southern European member states. Spain, Greece and Southern-Italy, additionally have lower wages then in the Netherlands, which would have implications for the attractiveness of creating hydrogen valleys in these countries.[156] Such conversation could intensify and for the Dutch industry this could have far reaching implications.

This chapter has analysed the challenges for the Dutch hydrogen supply chain. These include a shortage of green hydrogen molecules, market uncertainty, fossil-based hydrogen dominance, import barriers, diverse hydrogen use cases and their sustainability criteria, supply chain resilience and the impact of the ETS. The chapter has further highlighted the dangers of carbon lock-in, competition between member states and industry flight pertaining to the Dutch hydrogen landscape.

[156] Ibid – Interview 15 “Hydrogen Valley Expert”

Conclusion:

The global hydrogen landscape is undergoing significant changes, attracting increased attention for the molecule. The US' IRA, a new flagship regulation offering a $3 hydrogen production tax credit, has bolstered the American hydrogen business case. Rather than offering similar production subsidies, the EU has cultivated its own approaches, such as setting targets for hydrogen off-take, providing funds and grants like IPCEI's, and establishing the Hydrogen Bank which has committed the first €3 billion towards bridging the investment gap. The EU Hydrogen Backbone aims to further strengthen the hydrogen landscape through the establishing of transnational hydrogen grids between member states. The EU seeks to combine internal manufacturing of electrolysers with a 10 Mt of internal hydrogen production and deriving 10 Mt through imports.

This thesis has analysed the obstacles and opportunities inherent in establishing a Dutch hydrogen supply chain, as a crucial part of the EU hydrogen backbone, and assesses the potential for the Netherlands to emerge as a key North-West European hydrogen front runner. The paper has also examined why the Dutch are reinforcing their commitment to hydrogen – which should be seen as a strategy born out of necessity, rather than out of luxury, given the Dutch position as the EU's second-largest consumer of grey hydrogen and the looming renewable energy deficits relative to anticipated hydrogen demand by 2050.

The Hydrogen Roadmap, a strategy devised by the Dutch government in concert with an array of public and private stakeholders, is set to tackle this challenge. This roadmap emphasises the necessity of blue hydrogen to ensure a stable supply for industrial clusters and to mitigate the volume constraints related to green hydrogen, for which imports, offshore wind and electrolyser capacity would need to be scaled up. The Dutch government intends to adopt a hybrid approach for its hydrogen supply chain, aiming to rapidly scale up electrolyser capacity from the current 3 MW to 500 MW by 2025 and to 3-4 GW by 2030, an increase of a factor thousand. Concurrently, the government will ensure the use of SMR and ATR-techniques to address potential shortages due to the intermittency of wind energy.

The factors positively influencing the potential to become a hydrogen front runner include the Dutch natural gas infrastructure, which can be retrofitted for the hydrogen backbone. This infrastructure could in turn be leveraged to create a unique North-Western European hydrogen import and export hub, bolstered by maritime connectivity, such as that provided by the port of Rotterdam. This will facilitate trade of hydrogen and its derivatives with neighbouring Germany. Given Germany’s future plan to import half of its hydrogen demand from or via the Netherlands, this offers a clear accelerator for a leading position.

However, Dutch industrial clusters are not ready to transition from grey to green hydrogen and view blue hydrogen as an intermediate step. With estimates indicating that only 28% of total grey hydrogen used in Dutch industry can be decarbonised without substantial modification, it is plausible that the Netherlands will not make its RED III directive target of 42% green hydrogen use by 2030 without substantial investments and subsidies for off-take.

Several other roadblocks stand in the way of securing this hydrogen hub position. Indeed, the demand for renewable energy in the Benelux and Ruhr Area is expected to be substantial until 2050, making these regions some of the EU’s most challenging to decarbonise. While the substantial demand for hydrogen in these regions could stimulate the ramp-up of the hydrogen market, the likelihood of obtaining the required volume of green hydrogen either via imports or via local production is relatively low. These circumstances necessitate reliance on blue hydrogen in the short to medium term.

However, blue hydrogen poses its own set of unique problems to the Dutch hydrogen supply chain. As the paper highlights, a focus on blue hydrogen contradicts the newfound EU goals of achieving energy independence, extends the lease of life of fossil-fuels, and adds sunken costs for CCS installations, which have a lifetime of around 10-15 years. From an investment perspective, there are no use cases for CCS installations in the production chain of green hydrogen, rendering CCS installations in portfolios a liability for investors against a backdrop of a rapid transition towards green modes of production. This shift to green hydrogen production could be accelerated by such measures as the EU-ETS, which is projected to slowly close the price gap between both production methods of hydrogen. However, considering the numerous challenges associated with scaling up green hydrogen, it is conceivable that blue hydrogen could dominate the Dutch hydrogen landscape. This dominance could pose a formidable barrier to entry for green hydrogen.

In conclusion, it is vital to further comprehensively map out the different stakeholder involved in both modes of production. These interests of stakeholders do not necessarily align, and understanding this dynamic more elaborately can offer additional insights for the challenges ahead in the transition towards a green hydrogen economy. Such an understanding would play a crucial role in shaping the strategies and policies for the Netherlands and beyond.

Appendix A: Interview Summaries

Interview 1

Interviewer	**Pjotr Jacobs**
Interviewee	**Port Authority**
Job Description	**C-level**
Date	**26.05.2023**
Duration	**29:15**

What are the accelerators and inhibitors for the Dutch hydrogen supply chain?

One could argue that the Netherlands could be a leading player within the hydrogen landscape of the EU. This has to do with 6 reasons. One is the great offshore wind potential, second is the willingness of international partners to produce electrolysers, the third reason is that the industrial clusters are in close vicinity of the ports, fourth is the great natural gas infrastructure which could be retrofitted, the fifth reason is the storage capacity for hydrogen in salt caverns and the sixth reason is the expertise in molecules that the Netherlands has.

In the ports we are already thinking about the future, so in general, the LNG terminals that we have could in the future be used for hydrogen. With regard to the carrier of hydrogen we are waiting to see what will be most competitive. Currently, the Esbjerg declaration and the Oostende declaration are positive developments in which we are involved.

With regard to the obstacles, I would argue that the producers of hydrogen face uncertainty with regard to who will off-take the molecule. And the demand side faces uncertainty with regard to the cost of hydrogen. I would argue that Germany has come up with a good solution in the form of H2 Global. This would definitely deliver a good solution to the chicken and egg problem. It helps significantly that tenders for offshore wind were launched. If you guarantee that certain volumes of hydrogen would arrive in the ports, then this creates certainty, something that is very necessary. In general though, I would say that we have to speed up the transition in the Netherlands. Usually our strategy is that we turn every coin twice and therefore do not make any real choices, which slows us down significantly.

What about the blue versus green hydrogen discussion?

I think that with regard to blue and green hydrogen, we would need both. Blue hydrogen has some significant challenges but will be very important for our short-term goals and for the transition phase towards green hydrogen. The Northern ports of the Netherlands would produce significantly more hydrogen, whereas the southern ports would do rely more on imports and less on local production.

Interview 2

Interviewer	**Pjotr Jacobs**
Interviewee	**International Energy Company**
Job Description	**H2 project manager**
Date	**25.06.2023**
Duration	**1:03:02**

What are the accelerators for the Dutch hydrogen supply chain?

For the Dutch hydrogen case, the fact that we have great industrial demand for hydrogen can be considered an accelerator. Due to the fact that Germany and the Netherlands have significant demand for green molecules, we do not have to fear that there will not be any off-take in Germany and the Netherlands. This would ensure that there would be an off-taker for green hydrogen molecules directly as soon as the molecule lands in Rotterdam. Be it via import or via local production on the North Sea. The European legislations such as the Hydrogen Bank create additional funding for our hydrogen goals. The biggest driver for hydrogen is the electricity prices and due to the great offshore wind potential of the North Sea generally speaking we have a good position.

What are the inhibitors for the Dutch hydrogen supply chain?

One of the biggest problems for the production for blue hydrogen are the huge investments necessary. If you could natural gas directly, instead of blue hydrogen, then it would be significantly cheaper. Currently, it looks like everybody is investing in hydrogen, but in reality, most of the financial investment decisions have not been taken yet. Another significant problem is the import of hydrogen. The Netherlands has to be careful with regard to what carrier they will choose. If ammonia is regarded as the best cost-competitive hydrogen carrier short-term, then we might risk lock-in on this technology, while the jury is still out with regard to what could be the best carrier long-term. So, investment decisions have to be taken with utmost care. Another problem for the Dutch hydrogen supply chain and the same is true for the EU supply chain is connecting all elements of the supply chain together.

Interview 3

Interviewer	**Pjotr Jacobs**
Interviewee	**Hydrogen manager**
Job Description	**Infrastructure and Transportation Company**
Date	**24.05.2023**
Duration	**44:20**

What are the accelerators for the Dutch hydrogen supply chain?

If we look at the accelerators for the Dutch hydrogen supply chain, then the offshore wind potential on the North Sea is really it. It is the power plant of Northwestern Europe. Many countries around the North Sea are pushing for developing this energy source. Norway and Denmark could be exporting countries, whereas Belgium and Germany are importing hydrogen countries, whereas the Netherlands is both.

The Esbjerg declaration and the Oostende declaration are both signifiers of the cooperation between North-Western European hydrogen producers. We are working to develop the infrastructure necessary for facilitating the infrastructure backbone for such developments. This would require additional planning for the offshore electricity systems. There is still a lot of work to be done in this field. If we make interconnections between countries, then there remain important debates to be had with regard to who pays what.

Generally, 85% of the Dutch hydrogen infrastructure could be realised through the retrofitting of the existing natural gas infrastructure and it is estimated that this would cost around 1.5 billion. In reality, those costs might be higher, especially considering the recent developments and the resulting increase in costs for steel. But in general, the Dutch natural gas infrastructure is an accelerator for the Dutch hydrogen supply chain.

With regard to Germany, there is huge demand for green hydrogen, so the Netherlands could play a role in being the transit country for this hydrogen trade. But a lot depends on whether the Dutch hydrogen infrastructure is going to be developed on time. Germany could be supplied with hydrogen from different countries like Austria, France and others. If the Netherlands develops its Delta Rhine corridor, then we are the first mover and this position as a hydrogen hub with regard to Germany would be strengthened. I think that ammonia would be the first carrier of hydrogen imports. The question is whether we would crack ammonia and then transport the hydrogen, or whether we would transport ammonia via pipes directly to the end-user. There are specific demand sectors, such as the fertiliser industry, which is closely positioned to Rotterdam and would need ammonia.

What are the inhibitors for the Dutch hydrogen supply chain?

With regard to offshore wind, the scale-up is foreseen to be sufficient, but with regard to electrolysers many challenges persist as much capacity needs to be rolled out. The short-term gap between the targets for green hydrogen and the demand for the molecule are an important inhibitor as much is still unclear.

There are some issues with regard to the transport of ammonia as well. The choice of ammonia as a carrier would perhaps not fully utilise the already existing natural gas infrastructure that could be retrofitted for the use of hydrogen. Additionally, some municipalities have already made statements with regard to ammonia, which is perceived as dangerous, and they do not want the transportation of ammonia on their territory.

Another issue is that the EU is currently perhaps not the most attractive export market for green hydrogen because the requirements for what is considered green is too strict. The EU has set very stringent targets for what is green hydrogen. It could be that other countries outside of the EU have less stringent targets and could therefore count on the first green hydrogen volumes.

Interview 4

Interviewer	Pjotr Jacobs
Interviewee	Energy specialist
Job Description	Green Finance Institution
Date	12.05.2023
Duration	1:17:21

The role of hydrogen in the EU's hard-to-abate sectors.

Steel making is at a global level the biggest emitter. It accounts for 8% of emissions on a global level. It is 7% for cement. And oil and gas around 4%. Steel is therefore the most important hard-to-abate sector. Now, at the EU level steel is very important, even-though 50% or more of the production happens in China, and 8% happens in India. In the EU it is still very relevant, because it accounts for 22% of the industrial emissions in the EU. It is 4% of the total EU emissions. Most of these emissions come from coal, because steel production relies on coal. There are two main ways of making steel. The primary way (which accounts for 60% of the EU steel making process) is making virgin steel, which implies the use of a blast furnace, and this is powered (in most cases) with coal to reach the 1500 degrees to heat the limestone. This process is around 90% of the emissions of the steel sector. The problem is that the rest of the steel (40%) is produced through an electric arc furnace, which can be made with up to 100% of recycled steel or steel scrap. The first part of steel production, where most of the emissions are, can be decarbonised through hydrogen instead of coal. This is the most cost-effective option. There are other options, but those are currently more expensive.

What is really crucial right now with regard to primary steel making production, is that 74% of these blast furnaces that are coal based, needs reinvestment by 2030. So, in this decade, literally in the next 7 years, 3 quarters of the whole coal fleet-based blast furnaces need reinvestment. If these industries reinvest for these fossil-based production processes for the steel making process, the EU risks locking in for 20-30-40 years as these plants have a massive lifetime. Therefore, if we miss this window-of opportunity we have locked-in three quarters of the steel making in the EU. Hydrogen is the technology that will deliver the decarbonisation here. If you use fossil gas, it is much more expensive than hydrogen as of now, and it achieves only half of the emissions of coal. Coal has a lot of fugitive emissions, so this is where green hydrogen provides the solution for steel making process.

If we take a look at Tata steel, they say they are investing to arrive to green hydrogen, and this is the narrative for many EU industrial players. In the mean term however, they will go with gas and when hydrogen becomes more competitive, they will make the switch. However, I would make the case, that moving directly into hydrogen would be the best strategy. Projects like HYBRIT and H2GreenSteel are doing this and are already producing green steel. So, for the EU a lot has been happening, it would be the EU-ETS and the CBAM, which have just been finalised. What is happening is that under the ETS they have to pay for the CO2 emissions that they have, and industries can exchange with each other for the permits. To prevent carbon leakage, under the ETS, hard-to-abate sectors have been given free allowances to protect them, up until now they were 100% free allowances. Now to try and stop this, they have tried to introduce the CBAM, which could give the company an insurance, so no more free allowances, because the imports coming to the EU have to pay the same carbon price that the internal EU producers have paid. This is the game changer, the CBAM will start to be implemented. Now this is going to be a game changer, Arcelor Mittal and everybody who is based in the EU, is going to have to take into account that what they produce, and they have to pay this carbon price. Not only the emissions will need to reduce, but they will also have to take into account the price of the ETS, which now is around a €100 per tonne of emissions. Then this has implications beyond the EU. Now the EU steel industry hates this, they hate that they have to pay, the estimate of what they will have to pay by 2030, when the CBAM is not even fully implemented (by 2034), it will be around 14 billion euros of what they have to pay in carbon price. If they do not decarbonise, they will have to pay 14 billion euros under the current prices of the ETS. The industry has to now comply with the ETS and with the price and the other thing is that when they will now do this 74% renovation, but they now also risk stranded assets in their portfolio, the coal-based blast furnace, that has no business case in the EU. The other interesting thing is how do you finance, as an industry company, other than the subsidies that the EU is handing out, this transition. The solution could be going into sustainability linked bonds or green bonds. Many banks like the bank of France have said that they will not do any more investments in fossil fuel energies.

How can green hydrogen, considering the volume issue, be used to decarbonise the steel industry?

The latest EU legislation mostly focused on the targets of hydrogen, the REPowerEU, 50% imports and 50% production are not enough. Hydrogen is a so-called no-regret option for steelmaking, but all investments going there are going to have to be prioritised for certain sectors. So, the other thing is the need for off-take agreements, agreements that need to be signed before the product is delivered. When it will be more expensive to use hydrogen, the steel industry will for sure use hydrogen. A lot of steel making companies are looking at hydrogen clusters, some of these are located in Spain, so Arcelor Mittal is working with a hydrogen company, they have the plant near them in Spain, and the hydrogen being produced there has already been bought, and they will use this for their green hydrogen-based steel plant. We do not know how much hydrogen there will be, but there are already plans and agreements from steel makers with hydrogen makers to buy their hydrogen in the first place. In the Netherlands, the Dutch government was subsidising the electrolysers for direct use in the industry. It is important to ensure that the hydrogen already has an end use before it is being produced. Hydrogen should be used in the sectors where it makes most sense. Using the green hydrogen would be more expensive in the short term, and that is the role of subsidies and policies, we have to prioritise where it is needed the most. Steel is one of the high priority sectors. By 2030 there is the need for reinvestment, that if it is done in the right way you will have decarbonised 3 quarters of the most pollutant sector in the EU. The problem with this is that steel production in the EU is not very widespread. Germany is one quarter of the EU steel production. For chemicals it is the same. This means that some countries need to prioritise this more than others.

Interview 5

Interviewer	**Pjotr Jacobs**
Interviewee	**Government**
Job Description	**Policy Advisor**
Date	**12.05.2023**
Duration	**50:51**

Is the Netherlands a front runner in the European hydrogen landscape?

The cost price of hydrogen in the Netherlands is relatively competitive but could never compete with countries closer to the equator. The question is to what extent we will use blue hydrogen, which in the long-term is most likely going to have a significant role. When you have a high capture rate for CO2 then you can capture 90% of your CO2, almost the same as you will have in terms of life-cycle emissions of green hydrogen. If we examine blue hydrogen from this perspective, then suddenly the conversation changes. Currently, the EU is pushing for green, but the Netherlands is well-positioned to use blue hydrogen. Blue hydrogen could therefore be a long-term solution in my estimation, especially considering the considerable storage facilities for hydrogen in the Netherlands. It will be more an “and-and” story then a “or-or” story. It will be a situation for the Netherlands where we would use both.

What about natural gas and blue hydrogen?

Currently, we have the image that natural gas is very expensive and relatively unavailable. Although this is true for the short term, it is unlikely that this will remain the case long-term. If we look at how quickly the Netherlands has been able to reduce its natural gas use, and this is reflected throughout the EU, we will see a reduction of natural gas use EU wide. It will never be as cheap as it was, but we do expect it to go down significantly on the European market, which could easily result in blue hydrogen being increasingly a better product. Additionally, when we examine the volumes of blue hydrogen and green hydrogen, of course blue hydrogen will remain dominant. The production process of blue hydrogen is increasingly becoming cost-effective. With an increasing EU-ETS, the CCS projects in the Netherlands will only become more effective.

What is the relation between EU policy and Dutch policy on blue and green hydrogen?

The RED targets are the most important in terms of legislation. The Commission has pushed for 50% of green energy use in industry by 2030. The target has now been set for 42%. What is important to understand is that green hydrogen can be an obstacle for blue hydrogen. If you need to use increasingly more green hydrogen for industries, then the business case for CCS is increasingly unattractive, due to the lifetime of an average CCS project being 10-15 years. It will become difficult to make a return on your CCS projects. There is a difficult situation in which companies want on the one hand to develop CCS projects, but this is difficult considering the long-term goal of green hydrogen, but on the other hand they cannot transition towards green hydrogen, because the costs of green hydrogen are too high currently. So, this is the tension between blue and green hydrogen. The rules on additionality from the EU means that we need additional renewable capacity on the North Sea, but it also means that other applications cannot use this energy. So direct electrification would be hurt by this endeavour. Green hydrogen could be considered bad for the climate if you cannibalise green electricity from the electricity grid. This could have implications for heat pumps for example.

Where would we use the hydrogen first in the Dutch landscape?

In principle, the first thing is that we want to decarbonise hydrogen as a feedstock. In the Netherlands it is the case that from our current hydrogen use around 70% is located in two companies, these are YARA in Sluiskil and OCI in Chemelot and in Delfzijl with BIOMCN. Those two companies use the most hydrogen. The other big users are the refineries. Those companies will need decarbonisation first. This is a huge challenge as it is. Imagine that as the Dutch government, you would like to meet the 42% target, if you increase the total decarbonised hydrogen demand in the Netherlands, you will only increase the demand for the molecule without increasing the actual supply of decarbonised hydrogen. To decarbonise these sectors is already a huge task without adding additional targets.

What are the additional use cases for decarbonised hydrogen after its use to decarbonise hydrogen as a feedstock?

The shortage of decarbonised hydrogen molecules means that we firstly have to decarbonise hydrogen as a feedstock. And only after this is completed, we can start talking about other uses for hydrogen. The most important use case for hydrogen after decarbonisation of hydrogen as a feed stock would be mobility and aviation. Many commercial parties are interested in using hydrogen for sustainable aviation fuels. Other sectors like steel, paper, cement and ceramics could be a candidate for hydrogen use, but if electrical blast furnaces are more competitive for steel making, then it would be electrified. So, this is not something that we make policy for. But in the case of steel making, it seems that electricity is not a solution, so these sectors will only make use of hydrogen if it becomes price competitive. For now, there will not be government subsidies for the steel making process using hydrogen, if we cannot first decarbonise hydrogen as a feedstock in the sectors mentioned before. It is likely that these sectors will come last. Additionally, Tata Steel should first transform its current coke-based steel production towards natural gas, that would already be a huge improvement. The Dutch government cannot and should not subsidise the use of hydrogen in sectors that do not currently use the molecule as it is impossible to predict what the most cost-competitive solution in these sectors would be. Another important question is whether the use of hydrogen as a storage method for adjustable power would be in the interest of our society, if we need hydrogen in other sectors first. These are very tricky trade-offs.

What are the accelerators and inhibitors for the hydrogen value chain from a government perspective?

There are questions pertaining to which hydrogen carrier is going to be dominant. The problems surrounding import are mainly safety. Until 2030, ammonia imports of hydrogen will be dominant, and relatively little activity with regard to other carriers of hydrogen. Currently, our safety regulations do not take into account such volumes for ammonia imports. Surrounding the imports areas of ammonia, such as ports and railways, huge safety issues have to be dealt with. We could easily imagine how certain municipalities would revolt if they found out which volumes of ammonia would be imported via rail through their areas. This could have wide complications for the acceptation of hydrogen.

Interview 6

Interviewer	**Pjotr Jacobs**
Interviewee	**Port Authority**
Job Description	**C-level**
Date	**12.05.2023**
Duration	**27:54**

What are the accelerators and inhibitors for the supply chain of H2?

The business case for hydrogen in the Netherlands is potentially great. But if it really would be that excellent, then everything would already be in its implementation phase. Currently, there is no business case for hydrogen that is completely conclusive. The starting position for the Netherlands is great, we have an energy intensive industry, the right infrastructure and knowledge and know-how are there. But if you turn it around, you could also argue that even in a country like the Netherlands, with Gasunie, the petrochemical industry, the ports and the storage storage capacity present, it is difficult to launch the hydrogen ambitions.

What are the bottlenecks?

In reality, when we are discussing hydrogen, in the Netherlands for now it is mainly related to low-carbon or carbon-neutral hydrogen. Green hydrogen production is a very costly process, where the product that we create, is 3-5 times more expensive than the fossil alternative. This makes that the technology is not the problem, we can produce it, transport it, but to construct the green hydrogen supply-chain it is necessary that the price gap is bridged through for example subsidies on the production side, you can subsidise the demand side, everybody who uses green hydrogen will get some money at the pump, but you can also make certain usage mandatory, like in the aviation sector. On all of these levels work is being done. We have big subsidy programs that are being developed currently. We are also making the fossil fuel alternatives more expensive. Fossil fuels will be more expensive, green hydrogen will be subsidised and mandatory usage of the molecule will be set. This will have to make the price gap smaller step-by-step. This then should result in the fact that companies will make the jump from fossil fuelled hydrogen towards the green hydrogen variant. This is something that is especially seen in the ports.

We have the objective and luxury of being able to look towards the future because we are not so dependent on shareholders for our quarterly results, so we can look with a public view at what is necessary for the hydrogen infrastructure. Gasunie, network operators and port authorities are the front runners in making the hydrogen transition happen in the Netherlands. The first investments are coming from these public companies, after that we see that the chemical industry companies like HYCC and Shell are moving because they see that there is no alternative and because the infrastructure is there. The infrastructure is very critical for the whole endeavour.

In our port, the steel industry, which is currently powered by coal, needs make the step towards hydrogen, but also the aviation sector. The best chances for hydrogen are in those sectors as sustainable aviation fuels and in the steel industry. Long-haul trucking is another area where chances lie. The chemical industry could use hydrogen as a direct replacement of oil-based products.

How long will it take for the hydrogen market to develop?

The hydrogen market will not be realised in the next years. This is because the whole production chain has to be built up. There are no sizeable electrolysers in the Netherlands, the biggest electrolyser is 20 MW, but that is nothing. So, we are discussing gigantic volumes, that need to be imported, which means that we need hundreds of electrolysis capacity, but there is nothing of the sort yet. This has to built, the investment decision have still to be taken. So before 2030 this is a market that is completely being built up. After 2030, it would go very quickly, but it could grow exponentially. If we examine how carbon pricing will work, then we have an indication of how the fossil fuel prices will be. So I expect that the take off will take place. Additionally, from 2030 onwards most EU targets for the use of hydrogen will be definitive. So around that period everything will go fast. The next 5 years is mainly about executing the plans, and the period of 2030-35 will be critical.

Is hydrogen going to be green? And what risk of carbon-lock do we face within the green and blue hydrogen sector?

What I would argue is that yes there is a risk of carbon lock-in. We have to be very mindful of such developments, but at the same time, we need to acknowledge that what we all want is to produce green hydrogen. Then the question becomes, how can we produce green hydrogen as quickly as possible. First of all, we have to increase our renewable energy production. Why do we need hydrogen? Of course, direct electrification is necessary where that is possible, but not all sectors can be directly electrified and there we will use hydrogen (aviation, chemical industry, steel making etc). We have to try to bridge the gap between green hydrogen through the use of blue hydrogen, which is yes not ideal, but confronted with the fact that we need a short-term solution, it will be necessary. Green is not there in large scales, so we have to stimulate green hydrogen, tolerate blue hydrogen and to discourage grey hydrogen. Blue hydrogen will therefore have a place in our energy systems for 10-15 years and is a transition fuel. That is the time that we need to develop green hydrogen fully.

Interview 7

Interviewer	**Pjotr Jacobs**
Interviewee	**Lock-in specialist**
Job Description	**Research/Academia**
Date	**9.05.2023**
Duration	**16:28**

Do you see a risk for blue hydrogen and carbon-lock in?

The first thing that comes to mind regarding lock-in is that there is a contrast and conflict between blue hydrogen and green hydrogen. Blue hydrogen is just a way of producing hydrogen and uses CCS where green hydrogen is a completely different process that produces hydrogen through electrolysis. Carbon lock-in could occur if the energy system is going to shift from the blue hydrogen production towards green hydrogen. If you invest in CCS, you add sunken costs to the system when you are investing in your CCS installation. CCS is not completely commercialised today, but when everything is settled it will be easier to transport your CO2 for blue hydrogen production towards CCS. It is not that difficult for manufacturers to have this blue hydrogen production. But if you want to produce green hydrogen, you do not need this capture part so these assets will become stranded, as there is no use for CCS in green hydrogen production. This is the main thing that comes to mind if you consider blue and green hydrogen from the lock-in perspective.

How can lock-in be best understood from within the framework of supply chains like hydrogen?

Lock-in is not always a bad thing. It also saves time and money and it is a learning process, if you adopt a new technology, you learn about it and over time and you see the increasing returns as you get economies of scale.. Lock-in becomes bad when it becomes a carbon lock-in. This is when it prevents a transition from a polluting industry towards a decarbonised or renewable industry. What we are seeing related to deep decarbonisation in industry, is that we are dealing with a carbon lock-in. Anything that can delay or prohibit the system to shift from polluting fossil-based industry can be categorised as a source of carbon lock-in.

Do you consider CCS as a carbon lock-in?

In general, with regard to CCS, I do not see a black and white carbon lock-in, because with all the climate change goals and projections, we need CCS. But it becomes a threat or risk if it is not regulated. If fossil fuel-based industries are going to use CCS as an excuse to perpetuate fossil fuels, then it becomes a source of dangerous deep carbon lock-in. But if these fossil-fuel industries are looking at it as an intermediate tool or step, it is helpful. Many models are saying that it is impossible to reach deep decarbonisation without CCS. Therefore, it is very necessary for governments to regulate CCS and to make sure that we do not encourage over-usage of CCS to propagate a carbon lock-in.

Another good thing about CCS is that it is a fragmented supply chain, you can use the capture part, but reuse the carbon captured for the production of certain goods that require CO2. Currently, CCU is even worse in terms of commercialisation then CCS.

On a side note, another important factor to consider with regard to CCS is that currently we have in the Netherlands offshore wind energy being produced, but who will be the off-taker of offshore renewable electricity if the industry is taking the road of CCS and is not really using green hydrogen. In such scenarios the viability of producing the required amounts of offshore renewable energy would not really be in favour of green hydrogen.

Interview 8

Interviewer	**Pjotr Jacobs**
Interviewee	**Hydrogen Specialist**
Job Description	**Technical University**
Date	**5.05.2023**
Duration	**1:24:34**

What are the accelerators for the Dutch hydrogen supply chain?

The main question now is really where we would use hydrogen first. Do we go for the low-hanging fruits? How could we distribute the hydrogen when it becomes available? This is the main trade off in the Netherlands, but also on a European level. If you have renewable energy sources, should you use those directly, or should you use it for producing hydrogen and then where do you want to use it? There is a lot of confusion when it comes to hydrogen, because it is an energy carrier and not an energy source. Sometimes policy makers confuse this.

We need to make a picking order or merit order of what is the best approach. Again, it is a very difficult topic, and I am not saying that there is complete clarity as how to move foreword. With regard to the transport sector, aviation and heavy duty vehicles cannot run on batteries. With cars you should electrify, we really do not see hydrogen uses there. In shipping there are a lot of other energy carriers you could use. Ammonia is being discussed, methanol is being discussed. Most stakeholders in the ship manufacturing industry, see use cases for hydrogen only in the very distant future, whereas methanol and ammonia could be used in the short-term. For aviation there are no real alternatives. They really need the hydrogen to generate sustainable aviation fuel. Paper and pulp would additionally require electrons. Whereas cement and steel would need heat and that is something that you cannot electrify, because with electricity you cannot achieve these temperatures. There you would need hydrogen molecules. In the chemical industry these production plants run around the clock, so hydrogen could be used as a buffer. Ammonia is being looked at, but this is difficult as again you need hydrogen. With regard to households, you do not need hydrogen, especially when heat pumps are available.

What are the obstacles for the Dutch hydrogen supply chain?

The chemical industry and refineries need a lot of energy. They used to have very comfortable prices for natural gas and this was part of the reason why many factories were located in the Netherlands and Germany. The question is whether the industries remain if their energy prices become too high. There is a complicated and multi-layered push-and-pull between policy makers and industry. There is difficult discussion to be had with regard to competitiveness. The war in Ukraine additionally has highlighted problems associated with maintaining supply chains.

Interview 9

Interviewer	Pjotr Jacobs
Interviewee	Energy Consultancy
Job Description	Policy Advisor
Date	4.05.2023
Duration	32:01

What are the accelerators of the Dutch supply chain?

In the Netherlands we have our 5 industrial clusters and the Dutch government has indicated that these industries should be kept, but under the condition that they meet the Dutch climate targets. In these industries, there exist the sentiment that they want to decarbonise, but not for every price. This conversation is starting to intensify between the government and companies. The hydrogen demand in the Netherlands depends largely on whether industries choose to stay in the Netherlands. This ties in to the import dimension. If the hydrogen economy starts with sufficient hydrogen imports, then hydrogen will play a big role. But if the industries choose to leave the Netherlands, then, bigger issues arise of whether hydrogen will play a big role. The industry is therefore crucial for the Dutch hydrogen chances.

The advantage of blue hydrogen is that we are able to quickly decarbonise our societies. This would be an accelerator for the Dutch climate goals. The trade with Germany is an accelerator, but have to make sure that we do not lose tempo. Germany will develop alternative routes for hydrogen imports, this could take the form of their own ports (Hamburg or Antwerp).

Currently, the Netherlands already in the top three of hydrogen users in the EU, and therefore we have the advantage that all green hydrogen that comes here can immediately be used by the industry. This is a huge advantage as there is no need for demand creation. In other countries this hydrogen off-take is a huge element. But then we have to be very careful with regard to whether the industry stays in the Netherlands. If they leave, then this important driver would be gone. Therefore, it would be of importance to set clear targets for hydrogen use in the Dutch industries. If the industry leaves, additionally we would have to reimport these goods, and this might be a great problem.

What are the inhibitors of the Dutch supply chain?

With regard to the use of hydrogen in the building sector, there is strong case for hydrogen, but it is definitely not the case for light mobility and the heating sector. There hydrogen has definitely lost the race vis-à-vis the electricity sector. But indeed, in the building sector there are many possibilities long-term. The Dutch natural gas infrastructure can be reused for the hydrogen sector, it would be a shame not to use it, but there has to be enough hydrogen if the industry is going to be the primary target of hydrogen, and how long will it take to retrofit the natural gas infrastructure for hydrogen. There are plans to build a hydrogen backbone in the Netherlands, but this backbone currently only seeks to connect the five major industrial clusters and there is as of yet no talk about the lower distribution networks, the smaller pipelines that would go through the Dutch neighbourhoods.

The biggest argument against hydrogen is that it is inefficient. No matter how hard we try, this is a fact. But how important is this argument when we take into account that some countries have an over abundance of cheap renewable electricity. The biggest problem is how to transport this energy towards the Netherlands. Currently, this market is still small, but once we can ship green energy for a cost-competitive price, then efficiency is no longer an argument. Then with regard to the carrier, ammonia and LOHC, is currently already shippable, but in its liquid form its currently not possible.

With regard to which country would be able to ship large-scale renewable hydrogen towards us remains very unclear. Even-though the climate minister has made significant progress with regard to the MoUs with different countries this is not saying anything for now as long as there are no volumes coming our way. It only gives an indication of which partners are selected for future cooperation. Oman probably has the best cards to deliver Rotterdam with green hydrogen volumes. The cooperation with the port of Sohar, of which Rotterdam has a 50% stake, is an example of a solid Dutch hydrogen MoU. Currently there are discussion of importing this hydrogen from there on the short term. But again, Portugal or Morocco could be closer. But the jury is not yet out about which country is going to supply the Netherlands on the short term.

The big oil states have the possibility to produce hydrogen large scale, but as long as they are making significant revenue streams with hydrocarbons, why should they produce their maximum volumes of hydrogen if that hurts their main industry?

Interview 10

Interviewer	**Pjotr Jacobs**
Interviewee	**Policy Advisor**
Job Description	**International Advisory Association**
Date	**3.05.2023**
Duration	**1:21:20**

What are in the inhibitors for hydrogen supply chains?

We have to really be poking the needle in this hydrogen bubble. We have to be realistic. What are the realistic use cases of it? Obviously, the hydrogen pitch is bigger than life. Shipping hydrogen has to be done through ammonia, LOHC or other carriers and a lot of technical problems exist surrounding this. There is a lot of talk about the hydrogen economy, but the financing is not there. The RED II will be updated towards the RED III and so the policy landscape is always changing around hydrogen. Using hydrogen for busses, for vehicle transport and for trains, this is still being discussed, although this is not cost-effective. Take the example of Japan, they have all these plans of importing ammonia, but it is going to be very costly. But they do not have their own natural resources, so this has to be imported. So they are importing both the import products, which have to be green, but they cannot remain cost-competitive with a place like Australia, where they do have these resources and abundance of renewables. It is almost impossible to import resources and be cost-competitive in that aspect.

The hydrogen infrastructure is currently not there. There are big problems in terms of retrofitting natural gas pipelines for hydrogen, blending yes, it is possible up to 20%, but if we fully retrofit them to hydrogen it will be costly, that is the point I am making. Hydrogen naturally are molecules, but we have to continuously compare hydrogen with the benefits of direct electrification. I would like to stress that the transition from natural gas infrastructure to hydrogen sounds very logical. But if we examine the EU policy currently in place, like the RED II and the REPowerEU and then obviously the two delegated acts on the RFNBO's of which the two delegated acts are not officially adopted yet, are very crucial. It is additionality, where you need brand new renewable energy sources. In this sense, blue hydrogen and natural gas is not going to cut it. These policies are very stringent on green hydrogen, which it should be. By 2030, the EU wants to have 10 MT of hydrogen produced domestically, but also 10 MT of hydrogen imports. By my estimates that is 500TWh of renewable energy, which is currently significantly lower, and there is the electrolyser component of that. For that to work we would need 6000MW of electrolysers. Currently, in the EU, we have about 160 MW of electrolyser capacity, so to reach those targets we would need an increase of 38 times by 2025. When you look at that it should blow your mind, because it is not going to be possible. If we look at the investments from the big hydrogen backers, we see that currently these stakeholders do not invest in hydrogen with their own money, but are instead waiting for government money to come in. Another important point to make is that these hydrogen targets underneath RED II and the amendments proposed include 5.7% of all transport has a target of using RFNBO's. Currently it sits at 1%, so its an increase of 5% and this feeds in to this hype. Regardless of what the market says, maybe hydrogen becomes super expensive, still the target is mandated. The fact is direct electrification has less question marks then transforming our systems for the use of hydrogen. Hydrogen is really a house of cards. Why would we invest so much time and money into building out this hydrogen infrastructure if the basis is really renewables? Only when we have an excess of renewables then green hydrogen becomes interesting.

It is very impressive how many countries have adopted hydrogen strategies, and there is a lot of governmental policy around the world with regard to hydrogen. So absolutely, the hydrogen train has left the station, but how far is it going to go? The hydrogen lobby's main concern is pushing hydrogen, whether hydrogen actually benefits in a certain sector or not is a secondary aim. If we would have to belief the hydrogen lobby we could use hydrogen to brush our teeth. But is that effective? Hydrogen use in heating for houses is so expensive, not to talk about retrofitting houses for hydrogen use there. Heat pumps are way more efficient in this sector. The same for hydrogen use in light mobility. It is simply not efficient there. There has been research done to back this up. With regard to aviation, there would be a huge volume of hydrogen necessary to decarbonise this sector. Hydrogen also takes up a significant amount of space, so how do you transport that to an airport? The only way to pump the hydrogen there is to pump it as a gas, or to do electrolysis on site and you will need massive amounts of energy. 17TWh per day, for one airport, which would be 60% of the Dutch solar and wind generation. This is very problematic.

The EU carbon pricing plays a huge role in discoursing the use of fossil fuels. Currently, the EU-ETS is way too low. Renewable energy is the cheapest form of electricity. But if the carbon pricing increases, CCS becomes a necessity to meet climate targets. But you might as well turn this renewable electricity to produce green hydrogen. Therefore it is so important for the fossil fuel companies to keep the carbon prices low to continue extracting fossil fuels. The two delegated acts are very solid in making sure that hydrogen is green. It is not only domestic, but it is also applied internationally. It would be very interesting to keep a close watch on the progress within the EU. If the acts are passed it would be a good thing for the decarbonisation goals of the EU. If the EU keeps pushing for stringent green hydrogen policy then this would be the silver lining.

What are the accelerators?

There are of-course very rational use cases for hydrogen. These use-cases are very valid, but often not stressed enough. Hydrogen is going to be part of the energy landscape of the future. The most obvious case for hydrogen is to decarbonise our use of gray hydrogen. Currently we use 94 Mt of natural gas hydrogen worldwide. We need the molecule H2 in these sectors. There is a big role for green hydrogen there. Ammonia for fertilisers is the same. The third is storage.

The IRA versus the EU hydrogen policy:

The business in the US is stronger for hydrogen. The US is subsidising green hydrogen. If you are producing hydrogen in the US you get a $3 dollar tax credit. But the biggest difference to point out, is that a lot of what the EU is doing is prescribing targets. And the EU has funding and grants, IPCEI projects to support hydrogen infrastructure development, to build the hydrogen backbone, but the EU does not subsidise hydrogen production or hydrogen use. So the EU is spending a lot of money, but that does not mean people will use hydrogen. Whereas the IRA, also subsidises production.

Interview 11

Interviewer	**Pjotr Jacobs**
Interviewee	**Energy Specialist in Hydrogen trading**
Job Description	**C-Level**
Date	**28.04.2023**
Duration	**29:54**

What are the accelerators and inhibitors for the German hydrogen supply chain?

H2 Global and its operating arm, Hintco, are at the center of purchasing green hydrogen and bringing it outside of Germany. H2 Global is a foundation, and Hintco is a company that purchases hydrogen globally through tenders and auctions. We have three auctions planned for methanol, ammonia, and e-kerosene, with a budget of €9,000,000. By the end of the year, we aim to secure long-term contracts, potentially with countries like Chile and Australia, for hydrogen derivatives under Hydrogen Purchase Agreements (HPAs).

On a long-term scale, these contracts will last for about a decade. They will then be rescaled to the markets via one-year contracts to create liquidity. If we were to pass on a 10-year contract directly, it would be good for the user's stability, but it would also create a "closed shop," meaning we would have no idea how hydrogen pricing would work. To bring liquidity to the market and ensure a competitive approach, Hintco will use EEX to organise the auctions and will be responsible for long-term purchasing.

This auction is for the production of green hydrogen within the EU, but it will be for ten-year bilateral contracts with subsidies. The company asking for the least subsidy gets the money. However, this approach does not facilitate the creation of a hydrogen market. We are trying to convince the commission to adopt the H2 Global concept on an EU level.

A significant success in this initiative is that the Netherlands, which is often very market-oriented, strict, clear, and visionary, will join H2 Global. Austria and Belgium were also invited but they remained vague in their responses. It's also clear that there are diverging interests within the H2 lobby organisation and the founding companies, such as the owners of H2 Global.

We find ourselves in competition with other regions in the world, such as China and the US, which have certain subsidy schemes. It's unclear how Europe will respond to this. Can we bring down electricity prices? Can we offer the same subsidies? Can we win the race? These are the questions we grapple with. We support subsidised industries and provide them with cheaper energy prices, but the EU will not be able to match the prices in other parts of the world. Thus, we need to remain competitive and avoid dependence on other regions of the world.

A key factor to consider is that when H2 Global begins to purchase hydrogen, we will know when the hydrogen will be imported. The first imports are expected in 2024. It is also crucial to remember that ammonia is already traded globally. Some people forget this fact, but companies like YARA and Linde aren't interested in price transparency. Ammonia already exists today, and there is a market for it, although it's not transparent.

Regarding blue hydrogen, it's unfortunate that the discussion on nuclear has slowed down the Renewable Energy Directive (RED) by two years. While it's problematic to call nuclear green under the taxonomy, we also need to keep in mind that we'll be importing hydrogen. H2 Global focuses only on green hydrogen, although the Netherlands has proposed a case for blue hydrogen.

Inside Europe, there will be green auctions. H2 Global is lobbying to convince the commission to apply a similar scheme. We're taking a bottom-up approach, with the Netherlands being the first to join.

In the long-term industry outlook for the EU, we have to find a clever way to compete. However, trying to compete with the United States on electricity prices seems futile.

Interview 12

Interviewer	**Pjotr Jacobs**
Interviewee	**Hydrogen Research**
Job Description	**Academia**
Date	**21.04.2023**
Duration	**36:38**

What are the accelerators for the Dutch hydrogen supply chain?

The Netherlands is quite well positioned. It has an important potential for renewable energy production, generated through offshore wind. The power purchase agreements are quite low for offshore wind. The Rotterdam harbour allows for the import of hydrogen. The distribution pipeline network could distribute the industrial gasses around, which is quite an advantage. The high-volume storage capacities are an additional plus for the Netherlands in the form of the salt caverns and the natural gas fields in which hydrogen could be stored. If the Netherlands will start producing a lot, this will be an important accelerator. The LNG model and the H2 import model will also facilitate the development of the hydrogen industry. Additionally, if the European infrastructure and the Dutch infrastructure is harmonised, the Netherlands could count on extra financial support from the European Commission.
The Dutch MoUs with non-European actors could provide a significant boost for the Dutch hydrogen hub.

What are the inhibitors for the Dutch hydrogen supply chain?

With regard to the retrofitting of the existing Dutch natural gas infrastructure into hydrogen pipelines, it is important to examine closely what the costs would be for the large-scale retrofitting of these natural gas grids. It depends largely on the pressure, and you have to differentiate between the distribution network (the smaller pipes that carry gas from the transmission pipelines to individual homes) and the transportation network (the major pipelines that move natural gas from production sites to distribution networks). It will not be easy to install new pipelines. It is much easier to retrofit existing pipelines, not to mention the costs. With regard to the import dimension for the Netherlands, it would not be surprising that additional costs will be presented for getting the hydrogen molecules to the Netherlands. Therefore, I have my doubts with regard to the cost-competitiveness of importing green hydrogen towards the Netherlands. The time that your electrolysers would be running are very low. The additionality principle is another serious drawback for hydrogen production.

Blue versus green hydrogen?

The problem with blue hydrogen are the political issues surrounding it. The problem is really the political choice. Blue hydrogen would be a much better solution to launch the hydrogen economy as it is a lot cheaper. In the beginning it is a solution, but the problem is that subsidies will not go to blue hydrogen. If you take the cost of production of blue hydrogen which is €1.5 per kilo, which is much much lower than green hydrogen, so you can spend money to transport it.

Interview 13

Interviewer	**Pjotr Jacobs**
Interviewee	**H2 Technology Specialist**
Job Description	**Academia**
Date	**20.04.2023**
Duration	**50:45**

What are the accelerators for the Dutch hydrogen supply chain?

The hydrogen hub position of the Netherlands is likely to be a strong asset. The trade, facilitated through the Rotterdam port and the already existing infrastructure for hydrogen will be beneficial for the hydrogen trade with Germany. The countries are working together closely, this is reflected in the cooperation between research institutes, but also on a company level.

What are the inhibitors for the Dutch hydrogen supply chain?

The problem with ammonia is its toxicity. The problem with hydrogen is its explosive nature. We have the Hindenburg example, hydrogen is more flammable than natural gas. In the end, we figured out to handle natural gas, so if we know how to handle these molecules it can be safe, but the safety regulations have to be in place and currently we are not completely there, and this process needs to be sped up.

Renewable energy capacity for hydrogen production needs to be scaled up massively, which again is limited, due to the high electricity demand. Hydrogen is only relevant when there is a oversupply of renewable electricity. With regard to electrolysers, we have to tackle difficult problems with regard to whether we want bigger electrolysers or prefer to stack smaller electrolysers together. This is a policy issue and requires debates between large number of stakeholders.

Transport of hydrogen is another issue. If we start massively importing hydrogen via ships, the emissions of these ships have to be taken into account. Not to mention that currently there are almost no dedicated hydrogen transportation ships available and with regard to the EU import goals for hydrogen, questions need to be asked pertaining to what fuels these ships will run on? Will these ships run on hydrogen? Or will they run on dirty fossil fuels? These questions are as of yet largely unsolved. These aspects have to be better aligned with the Dutch and EU decarbonisation and hydrogen targets.

Another critical point is with regard to ethics, where countries like Tunisia and Morocco, but also others, from which hydrogen would be imported face difficult problems controlling the revenue streams of such a hydrogen trade with their European partners. It is something to keep in mind considering the scramble for hydrogen contracts worldwide. This will also affect the Netherlands.

Blue hydrogen

I do believe that blue hydrogen will have a strong role to play in the hydrogen scene in the Netherlands. This has to do with time issues for meeting our climate goals. It will take significant time for the green hydrogen supply chain to fully develop, and therefore blue hydrogen will play an interim goal. The industries that do not have any other option than to use hydrogen should use blue hydrogen on the short term, because it will at least alleviate carbon emissions. We cannot afford to lose more time.

Interview 14

Interviewer	**Pjotr Jacobs**
Interviewee	**Hydrogen Chemistry Specialist**
Job Description	**Senior Management**
Date	**23.01.2023**
Duration	**1:00:37**

What are the accelerators for the Dutch hydrogen supply-chain?

There are many question-marks with regard to hydrogen. Sometimes it is thought that the technology is already in a mature stage. But in fact, there are no large-scale electrolysers currently present in the world. Hydrogen is also not an energy source, but an energy carrier. We can ask ourselves the question if we will split hydrogen from ammonia, or whether we will use ammonia directly. If the EU is going to import large-scale hydrogen molecules in the form of ammonia, then the primary question is how to transport this. This would raise a lot of safety and regulatory questions, but it could be way more efficient than the transport of hydrogen itself. I think that many people have presumed that ammonia would be transformed within ammonia crackers to produce hydrogen, but I am not entirely convinced that this will be the best plan forward.

What are the limiting factors for the Dutch hydrogen supply-chain?

Hydrogen in the Netherlands, from our perspective, is mainly going to develop in the sectors where the value of hydrogen is the highest. Sectors that are hard-to-abate with other sources like electricity. The use of hydrogen will therefore be highest in the chemistry and steel industry and the heavy road transport in the Netherlands.

A significant problem for the Dutch hydrogen supply chain is storage. It is very difficult to store hydrogen due to the low energy density of the molecule. The Dutch HyStock cavern is only capable of storing a base load for a 500 MW electrolyser. If you want to build 10 GW in the Netherlands, you would need 20 of such HyStock projects to effectively store the hydrogen. The storage capacity therefore needs to be greater than for natural gas. This is a bottleneck. Therefore a solution would be to satisfy this huge hydrogen demand through the

SMR production process and through imports. Due to the intermittency of renewable capacity there are large amount of hours in which the electrolyser for green hydrogen could not be operational and this creates additional problems. In the end, the hydrogen demand of the hard-to-abate sectors in the Netherlands have to be base-load available and not only intermittently. All of these sectors have to be RED II compliant as well.

In the hydrogen sector, we need to create a harmonised cross-border hydrogen trade. This could be a part of the solution to alleviate the problems related to hydrogen storage.We have to acknowledge that through increased cooperation between the Netherlands and the North-Western European nations, we could alleviate some of the offshore and onshore intermittency problems. This is definitely a window of opportunity. The seasonal variation in the production capacity of renewables definitely has to be bridged through increased cooperation. There are stakeholders that want to develop offshore wind connectors between several countries to increase the production of hydrogen. But again, these developments are highly uncertain. Currently these discussions are highly speculative and not close to their implementation phase.

Additional problems can be found in the electrolyser rollout. Although we have many stakeholders engaged with this process, it is not like electrolysers are currently in their plug-and-play stage. There is currently no electrolyser active on an industrial scale. The whole design of the electrolyser includes chambers in which the electrolyser could explode if something goes wrong. These electrolyser designs are very new and it is not like this technology is fully mature. This is currently underestimated by the Dutch policymakers.

Interview 15

Interviewer	**Pjotr Jacobs**
Interviewee	**Energy Consultancy**
Job Description	**Hydrogen Valley Expert**
Date	**07.01.2023**
Duration	**1:05:20**

EU regulation on hydrogen valleys:

It is important to start with the reality that most goals of the EU, due to the huge energy demand in the EU, will not be met. In the Netherlands the goals of the Fit-for-55 and the REPowerEU roadmap will not be met. Only a few countries, like Norway and Sweden will meet these targets. This means that a lot of money will become available to scale-up hydrogen valleys. This money will be distributed through subsidies and guaranty mechanism such as IPCEI's and EU innovation funds. It is important to understand also that these hydrogen valleys will be most successful if they are connected to the EU's IPCEI's and to the hydrogen backbone which can only function if there are large scale hydrogen valley initiatives.

What is necessary to develop a hydrogen valley?

Hydrogen valleys or hubs as they are often called in the Netherlands, are a key part of the hydrogen supply-chain. This is really a European success story. In the EU there exist the ambitions of creating 100 of such hydrogen valleys. They are necessary to reduce our dependence on fossil fuel, through the local development of renewable energy sources. It is mainly a regional effort, but it is also a transnational operation that involves the cooperation between different stakeholders. Not every region is capable of organising such an effort without cooperation between other regions or transnational efforts. The development of a hydrogen valley is essentially developing a certain ecosystem that is difficult to organise due to the many companies and interests that need to work together. It is about developing a regional economic pillar. Some countries in the EU have to unlock their renewable energy potential through such valleys. There is a huge will for the development of these valleys and it is a tool to decarbonise EU regions. This hydrogen valley model is working well, but often there is significant resistance with regard to the organisational aspect in some EU countries.

The main problem is to find the right stakeholders, usually the larger companies are important for the success of such hydrogen valleys.

How competitive is the Netherlands with regard to other countries?

REPowerEU is a naturally a comprehensive framework, but every member state still has to develop the guidelines on their own. This creates friction as countries start to arrange their own deals. The Netherlands should play a bigger role within this perspective. Currently there is no pipeline connection between Norway and the Netherlands, which is a bottleneck for the Dutch hydrogen supply-chain. Additionally, there is the danger that due to relatively slow European hydrogen regulation, countries start to develop their bilateral hydrogen relations on their own accord. This plays into an increased EU competition for hydrogen strategies between countries. There is also increased competition with regard to the southern European nations, that have great renewable potential and are positioned closely to North African countries that could export hydrogen. Currently, Rotterdam has a great position, but there is a significant chance that this advantage will be diminished by the great renewable potentials of southern European member states. Spain has lower wages than exist in the Netherlands. This is the same for Greece and Southern-Italy. This has implications for good climates for hydrogen valleys. This could result in wealth-spreading throughout the EU. This is not good news for the investment climate in the Netherlands. Additionally, some companies like Arcelor Mittal and Tata Steel are considering moving out of Europe and move to India.

Hydrogen Backbone:

The hydrogen backbone can only function if the infrastructure for hydrogen is in place. Due to the war in Ukraine, changes have to be made with regard to the retrofitting of the pipelines that were imagined for hydrogen transportation. As natural gas will most likely play a role in the EU for the long-term, it has significant implications for the future hydrogen backbone. In the current context it could mean that the Netherlands has to develop additional hydrogen pipelines as the current pipelines will remain saturated by natural gas.

Interview 16

Interviewer	**Pjotr Jacobs**
Interviewee	**German Dutch cross border hydrogen expert**
Job Description	**Government Advisor**
Date	**05.01.2023**
Duration	**37:31**

The Dutch German relationship is an important topic. There are many issues that have a lot of EU relevance, but on hydrogen there is a lot of bilateral work that needs to be done between Germany and the Netherlands in the coming years. The Dutch-German relationship can be seen, for example, in the Delta Rhine Corridor project. Partners in Germany might be interested to facilitate cross-border connections and it is important to see where market chances lie for Dutch companies producing electrolyser components. The Netherlands is focused on national projects where cooperation with Germany could provide additional benefits. On the topic of hydrogen there are mutual interests in terms of import. Both countries would have to import a lot of hydrogen and the Netherlands wants to position itself as a hydrogen hub, which without the right cross-border infrastructure is not possible. Infrastructure also includes bilateral cooperation on storage to create flexibility. Both countries wish to be hydrogen technology exporters. Here additional chances for cooperation are present, mainly again in the sector of next-generation electrolysers. For both sides it is quite clear that the cooperation is something that is mutually beneficial, but there are a lot of questions and dilemmas still open. These include very near-term goals, 2027 hydrogen infrastructure connections and for 2030 the large-scale imports that need to be brought to Germany.

Do you think there is some sort of competition between both countries in terms of being a hydrogen technology exporter?

It is a bit of a mix, often the answer is that there is so much demand for the molecule that we are not competitors, also the export of technologies is a topic of hydrogen import that requires cooperation with third actors for hydrogen relations. Technology is a tricky area, because not all companies are open to talks, and in this sense there is some friction as both countries want to be hydrogen pioneers. In general, it is a very friendly relationship. A good example of this is the fact that the Netherlands is the first partner to join the German H2 global initiative with €300 million. There could be a Dutch German tender in the future to jointly purchase the hydrogen and import it through the Netherlands to Germany.

With regard to the imports is everything finalised?

There is an agreement that there is a huge need for imports, and especially for the Netherlands as energy hub, this is a great idea, but there remain open-ended problems with regard to the Dutch German hydrogen energy cooperation. Perhaps it would be a good idea to enter into purchase agreements from a EU level. There are enough options, but it would be strategic to align. There are many considerations to take into account. Additionally, what carrier, liquid or ammonia we choose are problems that need to be solved preferable from a unified EU perspective. There are a lot of plans available, but everything changed due to the new energy flows as a result of the Russian invasion of Ukraine. With regard to the infrastructure discussion there has been a revision of the Dutch hydrogen backbone plan to take into account that some pipelines are not going to be available for the near future. With regard to France there is also much more criticism with regard to the dependencies that hydrogen could bring. There should be more discussion on the import dimension of hydrogen in the new energy era.

With regard to hydrogen imports, it is additional a point of further inquiry to what extent the aim is to go to a few main suppliers, which would make the supply-chain easier, or do we pursue a more multilateral hydrogen trade with several partners to diversify our import supply-chain? This is more or less the same discussion with LNG. To what extent should joint-purchases be implemented on an EU level, the same discussion applies to the hydrogen field. In general, the hydrogen market should take the lessons from the LNG market into account.

Certification:

Additionally, there are many different systems for certification emerging that are relevant for hydrogen imports. A new certification pilot project was launched in the Netherlands called “HyExchange”. This topic is developed in the Pentalateral Energy Forum and the WWF. The Delegated Act will most likely play a role, but this is also a discussion where future exporting countries are critical. It is essential to examine the strict certification in the EU. This remains a point of contention that has important implications. CertifHy, a European project, wants to develop a certification system for the whole EU. In Germany people are waiting for the EU's certification process. This is an interesting topic as well, as many people argue that the EU does not have military power or soft power, but we do have standardisation power. The EU is able to push standards to other countries and it would be interesting how this would play out for hydrogen.

Competition with the Iberian peninsula and the Dutch-German industry:

Since the war, it is in all the speeches as well, there is the fear of losing industry due to the high prices for energy. Germany and France also had a joint statement about it with regard to the Inflation Reduction Act. It is too early to say whether whole industry sites would move, but it is true that it becomes less competitive for Germany and the Netherlands. It would be really interesting how that would work for old industry regions, like the Ruhr area, where all the steel industry has settled. They used to have a lot of coal. And today that industry is still there. Now the question is, is it maybe going to move to Spain, because there is a lot of space and there is cheaper energy available, but we should also think about other factors. It could be very interesting to investigate this further, what other factors play a role and is there any reason to belief that industries are going to move because of cheap energy as this could lead to huge movements of industries as the future energy landscape could look very differently from the industry today. As steel is very present in the Netherlands and Germany, and also relates to hydrogen in the sense that both governments realise that they need to supply sufficient rightly qualified hydrogen for these industries to make the required energy transformation. An additional question is often raised within the hydrogen import topic, why do we transport the hydrogen here, if we could also use the hydrogen in those countries and instead export those products to the EU. This year the EU will come with a new electricity market design, the basic need to revise it was to have a better uptake of renewables in our energy design. This also has implications for the Germany and the Netherlands, and it would be interesting to see what implications this has for the market developments in hydrogen in both countries.

Interview 17

Interviewer	**Pjotr Jacobs**
Interviewee	**Port Authority**
Job Description	**C-level strategist**
Date	**05.01.2023**
Duration	**37:31**

What are the accelerators and inhibitors for the Dutch hydrogen supply chain in the Dutch ports?

Hydrogen plays a long-term role for the Dutch ports. We have to acknowledge that the developments within the sector are developing quickly. I am mainly concerned with the hydrogen infrastructure, including high pressure hydrogen systems. This is of crucial importance for the end use sector. Of course, there are also hydrogen end-users that do not need such high-pressure pipelines, those will be connected through the distribution network (in the same way as the natural gas system in the Netherlands). As port authorities we are often the initiative taker, but in the end, we are not the party that develops the interconnections towards the ports, this would be HNS. With regard to the distribution network this would be taken care of by Alliander.

We came to the conclusion that we need additional hydrogen production in the port areas, we have developed this in cooperation with HyCC. With regard to hydrogen, the port authority is therefore mainly acting as a hydrogen-pusher, but we are not the actual producer or end-user of this hydrogen. We are active in all spheres of the hydrogen sector, including government, end-use, etcetera.

In the end, the EU policy has a leading role and this we monitor closely. Additionally, many projects are currently not ready for FDI, this will take place in 2023-2025. This timeframe allows for the development of the hydrogen policy. There are sufficient signals to develop the business case and to clarify which subsidy arrangements need to be taken.

The bottom line is that many companies have to transition towards other fuels, and do not always know what the costs for hydrogen would be. Currently, the cost of hydrogen in the mobility sector is significantly too high. What the exact price will be is unclear. This is one the key debates and puzzle pieces within the EU hydrogen policy. We have to also think about what the correlation between the production of hydrogen and the production of renewable energy should be. Now, we see that it will most likely be on a hourly basis. That is difficult, because as soon as the wind is not there and your electrolyser is sourced from a new wind-park, then you would have to shut down the plant immediately. This has implications for your CAPEX and your investment costs (CAPEX) which are not used in that moment. In the moments that you do produce, you will have to earn your investments back. In the end, if you cannot correlate it, it means you do not produce green hydrogen, so you could theoretically keep on producing by buying electricity from the net, but then you do not produce green hydrogen. So then you are directly competing with hydrogen made from fossil fuels. The subsidies are only for green hydrogen, and then there is a problem for the end-use sector who would not able to consume any green hydrogen. If you could only use 50% of your capacity in a year, it means that additional capacity needs to be rolled out swiftly.

Are we at risk of losing key-industries in the Netherlands?

The European approach is definitely the correct one, the one concern is if we stay competitive, but in general I think that it is better to develop the hydrogen sector correctly the first time. This is the case for the EU. Due to the CO2 border taxes, additionally, we are not entirely sure if American Hydrogen would be competitive in the EU. In my view, the US has a simplistic approach to boost the hydrogen market, whereas the EU tends to be perfectionist.

Carrier:

There has been some progress with regard to the carrier of hydrogen. Ammonia is currently a good option due to the existing market conditions for ammonia. The industry is also already familiar with ammonia. The question is whether we would crack ammonia to derive green hydrogen. For ammonia we would need high temperatures to crack, so that also costs a lot of energy. In the ports we are also examining Liquid hydrogen and LOHC (which you could crack at lower temperatures, but you are left with a rest-product that you could reuse to produce hydrogen), but ammonia has the advantage that it could also be used directly as a feedstock. Liquid hydrogen has the advantage that it is a very pure form of hydrogen, which is interesting for the mobility sector which requires a high purity of around 99.99%. But here the costs are the main issues due to the low temperatures in -270 degrees in which it should be transported. For us ammonia is complex, because it is a toxic substance, and in general the question, how do we deal with complex questions such as transport of this substance over long-distances over land. Some stakeholders might be scared about this. Do we additionally leave the carrier choice to the market, or do we set an EU-policy or national policy for the specific carrier for hydrogen? Do we make ammonia pipelines or do we transport it via rail? We have to closely watch the developments for the carrier. Everything is currently in favour of LOHC, which can use the current infrastructure, but logistically it would lead to high flows of this carrier which could be problematic.

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