HyDelta 3

WP2a – Standalone Hydrogen Areas in the Netherlands

D2a.1 – The role of standalone hydrogen areas in decentral hydrogen infrastructure development

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Document summary

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Executive summary

The role of hydrogen in the Dutch energy transition is vital. Therefore, multiple European and Dutch targets have been set for electrolyser capacity and renewable hydrogen off-take in industry and mobility by 2030. Hydrogen infrastructure is needed to facilitate this supply and demand. After the presentation of the HyWay27 report in 2021 [1], the Dutch government assigned HyNetwork Services (HNS, 100% subsidiary of Gasunie) as hydrogen transmission operator and allocated financial support. The construction of the first 32 km segment of pipeline in Rotterdam started in October 2023.

Still, the roll-out plan for decentral hydrogen infrastructure remains rather uncertain. There is a good picture on how decentral industries can be launching customers for creating branches from the backbone [2] and how areas in the regional gas grid can be converted from natural gas into hydrogen [3]. However, there are also regional hydrogen initiatives developing that aim to start without a pipeline connection to the central transmission system. This report defines those initiatives as 'standalone hydrogen areas' and has the main aim to describe if, and under what conditions, such areas can contribute to the successful roll-out of hydrogen infrastructure in the Netherlands.

A case study approach was used to investigate this question. 9 diverse standalone hydrogen areas were selected from approximately 40 potential projects (Figure 1) and information about these cases was gathered by 20 semi-structured interviews, project documents, and informal bilateral phone and email contact with stakeholders. The projects vary in maturity, and none are fully realised at present. The analysis has been conducted with this context in mind.

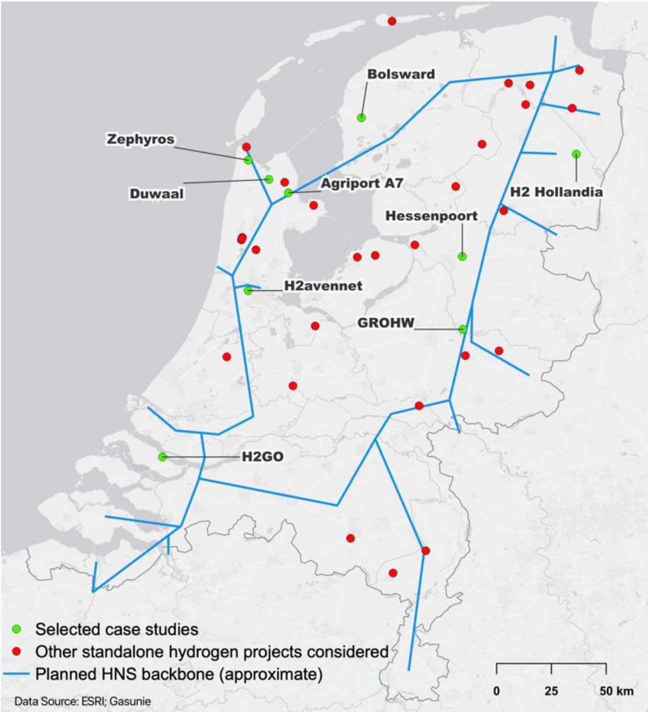

Figure 1. Selected case study locations and other standalone hydrogen projects considered.

The drivers behind standalone hydrogen areas varied among the projects, and often multiple drivers affected each project. Some of the principal drivers were the following: to decarbonise; deal with grid congestion; reduce curtailment of renewable energy; satisfy existing hydrogen demand (in areas where it remains too small for an HNS connection); and demonstrate a blueprint project. Similarly, there was a wide variation in case-specific enablers and barriers for the projects, which were distilled into the most important criteria for standalone areas: favourable off-take conditions; ample coordination within the project; availability of green hydrogen through import or local production. In the case of local production via electrolysis, availability of green electricity (either via sufficient grid connection or direct integration of renewables) is another must-have; subsidy funding; and government support. Several of these criteria are not unique to standalone areas but are characteristic of any hydrogen development. Additional criteria that were deemed nice-to-have, which are particularly important for standalone areas, are clarity regarding the timeline for backbone connection and leveraging synergies between hydrogen, oxygen, and heat off-takers.

Seven key roles were observed within each of the investigated decentral hydrogen projects: a project coordinator that keeps an overview of the whole project and all stakeholders involved; a key project driver that takes the initiative and serves as a driving force within the project; a knowledge sharing & advising body, which is often provided by grid operators or consultants; an energy balancer, which is typically an energy supplier in the bigger standalone projects and an off-taker in the smaller standalone projects; a permit provider, which is typically the regional government; the municipal government, that directly or indirectly includes the project as part of their regional strategy; and asset investors and operators, which are responsible for production, transport, and consumption.

The degree of DSO involvement in standalone areas varied. When involved, their technical expertise and coordination capacity were vital to effective hydrogen infrastructure roll-out or in dealing with limited electric grid capacity; when not involved, it was often perceived as a detriment to the project. However, in some cases it was positively perceived as an opportunity to operate without the less flexible and regulatory hurdles that accompany their involvement.

Local government involvement also varied across projects from minimal involvement to being a principal underlying driver by including the project in their regional energy transition strategy. The role of local government was perceived to be key for obtaining permits and in many cases for navigating economic, legislative, and societal barriers. In one case, the local government even planned to fill the gap left by the absence of a DSO in overseeing hydrogen distribution infrastructure.

Regulatory and legislative barriers were experienced in all the projects. Typically, the issue with existing regulations is their complexity, lack of clarity, and in some cases lack of alignment. It is furthermore often unclear whether the regulations will change and the expected timeline. Another issue is the slow pace of permitting and that such permitting periods are typically shorter than the duration of the business case. However, these issues are not unique to standalone hydrogen areas, but are similar to those faced by hydrogen projects in general.

The degree of hydrogen infrastructure roll-out within the projects varied and was often dependent on its long-term goals and whether a backbone connection is expected. Several projects plan to develop local hydrogen infrastructure to prepare the region well for a future backbone connection. Others plan to develop regional infrastructure to connect off-takers and producers despite an uncertain backbone connection and a potential to remain standalone. And some projects do not intend to develop regional infrastructure other than a tube trailer filling station or an HRS.

For the projects that intend to develop a regional hydrogen grid, a distinction can be made between low (<16 bar) and high (>16 bar) pressure grids. For projects in which a DSO is involved for the development of infrastructure, the grid will operate at a maximum pressure of 16 bar, as they presume pressure operating limitations, like those for natural gas distribution, will be imposed on them in the future. Such a grid would be sufficient for off-takers planning to use hydrogen in industrial boilers as that requires low pressures (max 4 bar). Additionally, a relatively low-pressure grid is preferred for feed-in from an LOHC terminal. On the other hand, some projects prefer a high-pressure grid to prevent unnecessarily depressurizing and then compressing hydrogen for end-use in mobility or to adapt to the backbone. Besides, a high-pressure grid means an increased capacity of the network. The total volume of hydrogen in standalone areas is typically based on the expected demand within the area and does not exceed 30 MW. However, the H2avennet and Zephyros projects located in port areas are exceptions and expect capacities to increase to 500 MW and 200 MW, respectively, although the Zephyros project only expects this increase after a backbone connection. The quality of hydrogen produced in standalone areas is typically fuel cell-grade. Challenges arise for high-quality hydrogen end-users (e.g., mobility) when a connection to the backbone (purity 98 - 99.5%) is foreseen, as it is currently unclear who should be responsible for the required purification step.

Congestion in the electricity grid is a big issue in the Netherlands and can be a major barrier for the development of standalone hydrogen regions. Some projects were already impacted by grid congestion and had to reduce the size of their electrolyser. However, innovative methods were also adopted by several projects to deal with grid congestion, such as sharing grid connections and reducing electricity size needs. Potential opportunities to provide local grid balancing services with decentral hydrogen production are being considered but no demonstrable progress has been made.

The viability and potential of standalone hydrogen areas was assessed based on the major end-users within the projects: mobility, industry, and built environment. Standalone projects with mobility end-users are potentially viable due to the high hydrogen purity within these projects and the relatively low seasonal variability and, therefore, relatively low hydrogen storage requirements. However, lack of commitment to hydrogen from potential off-takers in the mobility sector due to high hydrogen prices presents a significant challenge to the business case. Industrial off-takers can become relatively flexible in off take, which stimulates local hydrogen grid development. Areas with industrial off-takers are likely viable, but only to a certain extent as not all industrial end-users in such an area can plan to switch completely to hydrogen before a backbone connection can provide security of supply. Standalone projects for built environment end-users will likely not be viable due to the mismatch between the production profile of the electrolyser and the demand profile of the consumers and the strict regulations regarding high security of supply for household heating.

The role of the backbone connection and the expected costs of locally produced hydrogen compared to large-scale centrally produced hydrogen were both considered when assessing the viability of standalone hydrogen areas. Overall, most projects do not plan to be standalone in the future but anticipate relying on a connection to the backbone (assuming adequate production and storage) for security of supply. While some projects developed knowing with certainty a backbone connection would be realised, others perceived standalone operation to be necessary to develop the local hydrogen economy and scale demand to meet the threshold necessary for obtaining an HNS connection in the future.

Some projects do not rely on the backbone connection but still expect a positive business case, indicating that standalone projects can be economically viable. However, this does include subsidies and without support schemes none of these projects could present a positive business case. A significant challenge for locally produced hydrogen is to compete cost-wise with large-scale centrally produced hydrogen, as the general sentiment is that locally produced hydrogen is expensive.

Finally, the four main typologies of standalone hydrogen areas identified in this research are discussed. The distinction between these typologies is made based on their primary hydrogen source (electrolysis or other) and the primary hydrogen application (fuel cell or other), because these distinct its design choices. The first typology is standalone hydrogen areas primarily sourcing hydrogen from a local electrolyser for fuel cell applications. These are often relatively small-scale projects that typically use tube trailer transport. The second typology is standalone hydrogen areas primarily sourcing hydrogen from a local electrolyser for applications other than fuel cells, typically hydrogen burners. Transport is foreseen using new hydrogen pipelines next to existing natural gas pipelines. The final two typologies are standalone hydrogen areas that source hydrogen by a different method than electrolysis with end-use in fuel cells (third typology) or other applications (fourth typology). Although the projects can, especially in their initial phases, be generally divided into these typologies, they are not set in stone;

as the projects develop further and new producers or consumers are added, aspects of multiple typologies can be observed. From the typology analysis, building blocks were distilled that clearly show the relations between how different hydrogen sources and applications impact the decisions on technical characteristics, system balancing and selected transport modes in specific parts of the standalone area.

In conclusion, standalone hydrogen areas can play an important, but niche, role in the roll-out of hydrogen infrastructure and the broader hydrogen transition plan for the Netherlands. Standalone areas must fit within their local context and are likely to be viable only when key characteristics are met. Given the relatively small number and scale of such areas at present, the extent of their (further) development and degree of their impact on the energy transition remains to be seen.

Samenvatting

De rol van waterstof in de Nederlandse energietransitie is cruciaal. Daarom zijn er meerdere Europese en Nederlandse doelstellingen vastgesteld voor elektrolyse capaciteit en het gebruik van hernieuwbare waterstof in de industrie en mobiliteit tegen 2030. Waterstofinfrastructuur is nodig om deze vraag en aanbod te faciliteren. Na de presentatie van het HyWay27-rapport in 2021 [1], heeft de Nederlandse regering HyNetwork Services (HNS, een dochteronderneming van Gasunie) aangewezen als landelijke waterstoftransmissie-exploitant en financiële steun toegekend. De bouw van het eerste 32 km lange pijpleiding tracé in Rotterdam begon in oktober 2023.

Echter blijft het uitrolplan voor decentrale waterstofinfrastructuur nogal onduidelijk. Er is een goed beeld van hoe decentrale industrieën als 'launching customer' kunnen fungeren voor het creëren van aftakkingen vanuit het centrale netwerk [2] en hoe gebieden in het regionale gasnet kunnen worden omgezet van aardgas naar waterstof [3]. Er zijn echter ook regionale waterstofinitiatieven in ontwikkeling die tot doel hebben te starten zonder een pijplijnverbinding met het centrale transmissiesysteem. Dit rapport definieert die initiatieven als 'zelfstandige waterstofgebieden' en heeft als voornaamste doel te beschrijven of, en onder welke voorwaarden, dergelijke gebieden in het algemeen kunnen bijdragen aan een succesvolle uitrol van waterstofinfrastructuur in Nederland.

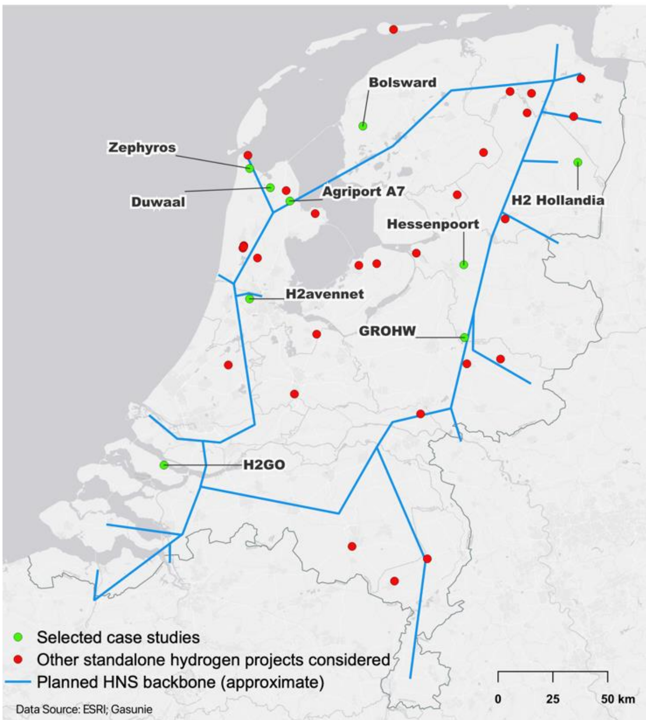

Figure 2. Geselecteerde casestudylocaties en andere op zichzelf staande waterstofprojecten worden overwogen.

Een case studie benadering wordt gebruikt om deze vraag te onderzoeken. Er worden negen diverse op zichzelf staande waterstofgebieden geselecteerd uit ongeveer veertig potentiële projecten (Figure 2) en informatie over deze gevallen wordt verzameld door twintig semi-gestructureerde interviews, projectdocumenten en kleiner bilateraal telefoon- en e-mailcontact. Tijdens de analyse is rekening gehouden met het feit dat deze projecten verschillen in volwassenheid en dat geen van hen nog volledig is gerealiseerd.

De drijfveren achter zelfstandige waterstofgebieden verschilden per project en vaak waren er meerdere van belang. De belangrijkste drijfveren waren de volgende: decarbonisatie; omgaan met netcongestie; vermindering van de afschakeling van hernieuwbare energie; voldoen aan de bestaande vraag naar waterstof (in gebieden waar deze nog te klein is voor een HNS-verbinding); en het demonstreren van een blauwdrukproject. Op dezelfde manier was er een grote variatie in case-specifieke facilitators en barrières voor de projecten. Dezen werden herleid tot de belangrijkste criteria voor zelfstandige gebieden: gunstige voorwaarden voor afname; voldoende coördinatie binnen het project; beschikbaarheid van groene waterstof via import of lokale productie. In het geval van lokale productie via elektrolyse is beschikbaarheid van groene elektriciteit (via voldoende netverbinding of directe integratie van hernieuwbare energieën) ook een vereiste; subsidiëring; en steun van lokale overheden. Verscheidene van deze criteria zijn niet uniek voor zelfstandige gebieden maar zijn kenmerkend voor elke waterstofontwikkeling. Wat opvalt is dat het lang niet altijd geografische karakteristieken zijn, maar ook zachtere factoren spelen een aanzienlijke rol. Aanvullende criteria die als prettig werden beschouwd, en met name belangrijk zijn voor zelfstandige gebieden, zijn duidelijkheid over de tijdlijn voor aansluiting op de waterstof backbone en het benutten van synergiën tussen afnemers van waterstof, zuurstof en warmte.

Binnen elk van de onderzochte decentrale waterstofprojecten werden zeven belangrijke rollen waargenomen: een projectcoördinator die het overzicht houdt over het hele project en alle betrokken stakeholders; een belangrijke project sturende kracht die het initiatief neemt en als drijvende kracht fungeert binnen het project; een kennisdelings- en adviesorgaan, bijvoorbeeld door netbeheerders of adviseurs; een balansverantwoordelijke, die typisch een energieleverancier is in de grotere zelfstandige projecten en een afnemer in de kleinere zelfstandige projecten; een vergunningverlener, namelijk de regionale overheid; een overheidspartij, die het project direct of indirect opneemt als onderdeel van hun regionale strategie; en investeerders en exploitanten van activa, die verantwoordelijk zijn voor productie, transport en consumptie.

De mate van betrokkenheid van de DSO bij zelfstandige gebieden varieerde. Wanneer ze betrokken waren, waren hun technische expertise en coördinatiecapaciteit essentieel voor een effectieve uitrol van waterstofinfrastructuur of bij het omgaan met beperkte capaciteit van het elektriciteitsnet; wanneer ze niet betrokken waren, werd het vaak gezien als een nadeel voor het project. Echter, in sommige gevallen werd het positief gezien als een kans om te opereren zonder de minder flexibele en regelgevende obstakels die gepaard gaan met hun betrokkenheid.

De betrokkenheid van de lokale overheid varieerde ook per project, van minimale betrokkenheid tot een belangrijke onderliggende drijvende kracht door het project zelf te initiëren als onderdeel van de regionale energiestrategie. De rol van de lokale overheid werd gezien als essentieel voor het verkrijgen van vergunningen en in veel gevallen voor het omzeilen van andere economische, wettelijke en maatschappelijke obstakels. In één geval voorzag de lokale overheid zelfs om mede eigenaar te worden van de waterstofinfrastructuur.

Regelgevende en wettelijke barrières deden zich voor in alle projecten. Typisch is het probleem met bestaande voorschriften hun complexiteit, gebrek aan duidelijkheid, en in sommige gevallen gebrek aan afstemming. Bovendien is het vaak onduidelijk of de regelgeving zal veranderen en hoe lang het zal bestaan. Een ander probleem is het trage tempo van vergunningverlening en dat dergelijke vergunningsperioden typisch korter zijn dan de duur van de business case. Deze problemen zijn echter niet uniek voor zelfstandige waterstofgebieden, maar zijn vergelijkbaar met die waarmee waterstofprojecten in het algemeen worden geconfronteerd.

De mate van uitrol van waterstofinfrastructuur binnen de projecten varieert en is vaak afhankelijk van de lange termijndoelen en of een verbinding met de backbone wordt verwacht. Verscheidene projecten plannen lokale waterstofinfrastructuur te ontwikkelen om de regio goed voor te bereiden op een toekomstige verbinding met de backbone. Anderen ontwikkelen regionale infrastructuur om afnemers en producenten te verbinden, ondanks de onzekerheid of een verbinding met de backbone zal komen of dat ze zelfstandig blijven. Daarnaast hebben enkele projecten niet de intentie om regionale infrastructuur te ontwikkelen anders dan een vulstation voor tube-trailers of een HRS.

Voor de projecten die van plan zijn een regionaal waterstofnet te ontwikkelen, kan onderscheid worden gemaakt tussen lage (<16 bar) en hoge (>16 bar) druknetten. Voor projecten waarbij een DSO betrokken is bij de ontwikkeling van de infrastructuur, zal het netwerk opereren bij een maximale druk van 16 bar, omdat zij vermoeden dat drukbeperkingen, zoals die voor de distributie van aardgas, in de toekomst aan hen zullen worden opgelegd. Zo'n netwerk zou voldoende zijn voor afnemers die van plan zijn waterstof te gebruiken in industriële ketels omdat dit lage drukken vereist (max 4 bar). Bovendien heeft een relatief laagdruknet de voorkeur voor invoeding vanuit een LOHC-terminal. Aan de andere kant geven sommige projecten de voorkeur aan een hogedruknet om onnodige drukverlaging en vervolgens het comprimeren van waterstof voor eindgebruik in mobiliteit te voorkomen. Het totale volume waterstof in zelfstandige gebieden is doorgaans gebaseerd op de verwachte vraag binnen het gebied en overschrijdt niet de 30 MW als een elektrolyser de enige bron van waterstof is. De H2avennet en Zephyros projecten gelegen in havengebieden zijn echter uitzonderingen vanwege de grote aanlandingspotentie van elektriciteit, en verwachten capaciteiten te verhogen naar respectievelijk 500 MW en 200 MW. Het Zephyros project verwacht deze toename pas na een verbinding met de backbone. De kwaliteit van waterstof geproduceerd in zelfstandige gebieden is doorgaans brandstofcelwaardig, omdat meestal elektrolysers worden beoogd. Er zijn uitdagingen voor eindgebruikers van hoogwaardige waterstof (bijvoorbeeld mobiliteit) wanneer een verbinding met de backbone (zuiverheid 98 - 99,5%) is voorzien, omdat het momenteel onduidelijk is wie verantwoordelijk moet zijn voor de vereiste zuiveringsstap.

Congestie in het elektriciteitsnet is een groot probleem in Nederland en kan een belangrijke belemmering zijn voor de ontwikkeling van zelfstandige waterstofgebieden. Sommige projecten werden al getroffen door netcongestie en moesten de omvang van hun elektrolyser verminderen. Echter, innovatieve methoden werden ook toegepast door verschillende projecten om met netcongestie om te gaan, zoals het delen van netwerkverbindingen en het verminderen van de behoefte aan elektriciteit. Potentiële mogelijkheden om lokale netbalanceringsdiensten te leveren met decentrale waterstofproductie worden overwogen, maar dit staat vaak nog in de kinderschoenen.

De haalbaarheid en potentie van zelfstandige waterstofgebieden werd beoordeeld op basis van de belangrijkste eindgebruikers binnen de projecten: mobiliteit, industrie en bebouwde omgeving. Zelfstandige projecten met eindgebruikers in mobiliteit zijn potentieel levensvatbaar vanwege de hoge waterstofzuiverheid binnen deze projecten en de relatief lage seizoensgebonden variabiliteit en daardoor relatief lage waterstofopslag vereisten. Echter, gebrek aan interesse van potentiële afnemers in de mobiliteitssector vanwege hoge waterstofprijzen vormt een significante uitdaging voor de business case. Industriële afnemers kunnen relatief flexibel worden in afname van waterstof als zij bijmengen, wat kansen biedt voor de ontwikkeling van lokale waterstofnetten. Gebieden met industriële afnemers zijn daardoor waarschijnlijk haalbaar, maar slechts tot op zekere hoogte, omdat niet alle industriële eindgebruikers in een dergelijk gebied volledig over kunnen schakelen op waterstof voordat een verbinding met de backbone leveringszekerheid kan bieden. Zelfstandige projecten voor eindgebruikers in de bebouwde omgeving zullen waarschijnlijk niet haalbaar zijn als de enige waterstofbron een elektrolyser is. Dit, vanwege de discrepantie tussen het productieprofiel van de elektrolyser en het seizoensgebonden vraagprofiel van huishoudelijke verwarming. Voor dit type zelfstandige waterstof gebieden zal gekeken moeten worden naar andere bronnen van waterstof.

Bij het beoordelen van de levensvatbaarheid van zelfstandige waterstofgebieden werden zowel de rol van de backbone als de verwachte kosten van lokaal geproduceerde waterstof, vergeleken met grootschalig centraal geproduceerde waterstof, in overweging genomen. Over het algemeen zijn de meeste projecten niet van plan om in de toekomst zelfstandig te zijn, maar verwachten ze te verbinden met de backbone om (onder voorbehoud van voldoende productie en opslag) leveringszekerheid te garanderen. Sommige projecten zijn relatief zeker dat zij in de toekomst met de backbone verbonden worden, terwijl anderen de opbouw van zelfstandige activiteiten als noodzakelijk zien om de lokale waterstofeconomie te ontwikkelen en de vraag te schalen naar wat nodig is om in de toekomst een HNS-verbinding te verkrijgen.

Daarnaast zijn er projecten die puur opzichzelfstaand beoogd worden en geen backbone verbinding behoeven in de toekomst. Ook deze projecten verwachten een positieve business case, wat aangeeft dat ook langdurig zelfstandige projecten economisch haalbaar kunnen zijn. Net als alle andere projecten hebben deze projecten in deze fase van waterstofontwikkeling nog subsidie nodig. Een aanzienlijke uitdaging voor lokaal geproduceerde waterstof is om kostenefficiënt te concurreren met grootschalig centraal geproduceerde waterstof gezien deze laatste gebruik kunnen maken van schaalvoordelen.

Tot slot worden de vier belangrijkste typologieën van zelfstandige waterstofgebieden besproken die in dit onderzoek zijn geïdentificeerd. Het onderscheid tussen deze typologieën is gebaseerd op hun primaire waterstofbron (elektrolyse of anderszins) en de primaire waterstoftoepassing (brandstofcel of anderszins), omdat hier de meeste ontwerpkeuzes van afhankelijk zijn. De eerste typologie is zelfstandige waterstofgebieden die voornamelijk waterstof betrekken van een lokale elektrolyser voor brandstofceltoepassingen. Dit zijn vaak relatief kleinschalige projecten die doorgaans tube-trailervervoer gebruiken. De tweede typologie is zelfstandige waterstofgebieden die voornamelijk waterstof betrekken van een lokale elektrolyser voor toepassingen anders dan brandstofcellen, meestal waterstofbranders. Vervoer wordt voorzien via nieuwe waterstofleidingen naast bestaande aardgasleidingen. De laatste twee typologieën zijn zelfstandige waterstofgebieden die waterstof verkrijgen via een andere methode dan elektrolyse met eindgebruik in brandstofcellen (derde typologie) of andere toepassingen (vierde typologie). Hoewel de projecten, vooral in hun beginfase, over het algemeen kunnen worden onderverdeeld in deze typologieën, zijn ze niet in beton gegoten; naarmate de projecten zich verder ontwikkelen en nieuwe producenten of consumenten worden toegevoegd, kunnen aspecten van meerdere typologieën worden waargenomen. Uit de typologie-analyse zijn bouwstenen gedistilleerd die duidelijk laten zien hoe verschillende waterstofbronnen en -toepassingen de beslissingen beïnvloeden over technische kenmerken, systeem balanceren en geselecteerde transportmodi in specifieke delen van het zelfstandige gebied.

In conclusie kunnen zelfstandige waterstofgebieden een belangrijke, maar niche rol spelen in de uitrol van waterstofinfrastructuur en het bredere waterstoftransitieplan voor Nederland. Zelfstandige gebieden moeten passen binnen hun lokale context en zijn waarschijnlijk levensvatbaar alleen wanneer essentiële kenmerken worden vervuld. Gezien het relatief kleine aantal en schaal van dergelijke gebieden op dit moment, moet nog worden gezien in hoeverre ze (verder) zullen worden ontwikkeld en welke impact ze hebben op de energietransitie.

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1. Introduction

The Dutch government has identified a strong role for hydrogen to play in its energy transition strategy, with a focus on deployment in industry, balancing of energy supply, mobility, and possibly to a limited-degree in the built environment [4]. The Netherlands is uniquely positioned to accelerate the hydrogen economy due to the present energy demand from processing industry, favourable conditions for largescale offshore wind deployment, and existing gas infrastructure and industry knowledge.

Previous research has determined that a national transmission network for hydrogen will be necessary, and has explored the degree to which existing natural gas infrastructure can be utilised, and what role government will play in the development of such a network [1]. Plans have been established for developing the Dutch Hydrogen Backbone (or *Waterstofnetwerk Nederland*) (hereafter referred to as "the backbone"), a project managed by HyNetwork Services (HNS) (a 100% subsidiary of N.V. Nederlandse Gasunie), which aims to provide high-pressure hydrogen transmission infrastructure between the 5 main industrial clusters of the Netherlands.

Decentral industries have been shown to be potential launching customers for creating branches from the backbone [2] and regional gas grids can be converted from natural gas to hydrogen [3]. Although the national government has alluded to the importance of making hydrogen available to industries outside of the main industrial clusters (also known as the sixth industry cluster or *het zesde cluster*), and also for other uses such as mobility, there remains much uncertainty as to the timing and detailed plans for availability of such infrastructure. For instance, TKI Nieuw Gas has indicated that further developing decentralised production and consumption of hydrogen in areas with local demand that are burdened by electric grid (e-grid) congestion is one of the five main innovation priorities for the coming years [5]. Nonetheless, existing decentralised projects are often in early stages and lack the same degree of involvement from the national government as the backbone project, leading to uncertainty of how the decentral hydrogen landscape will materialise.

The importance of transparency around future decentral hydrogen infrastructure plans cannot be overstated, as many industry and mobility stakeholders are facing pressure to decarbonise but are still unaware of what infrastructure will be available in the coming years, which complicates long-term investment decision-making. Moreover, e-grid congestion in the Netherlands limits the degree to which decarbonisation can be achieved through electrification alone, thus underscoring the importance of regional hydrogen development [6].

Standalone hydrogen areas present an opportunity to serve decentral hydrogen demand and simultaneously facilitate the roll-out of regional hydrogen distribution infrastructure before a connection to the backbone is established.[1] For the purposes of this research, we define a standalone hydrogen area as a geographic area (unspecified in size) where hydrogen is produced and consumed, with assets owned by at least two distinct parties, which initially will operate without a direct pipeline connection to the backbone. The term standalone does not imply that a connection to the backbone is not being explored or even undergoing development. On the contrary, standalone areas can often be pre-cursors to future regional backbone connections.

Accordingly, the development of standalone hydrogen areas could be a suitable solution for cluster six industry or mobility stakeholders to meet ambitious decarbonisation targets before a pipeline

[1] Decentral hydrogen demand (or production) refers to that which occurs in areas without a direct pipeline connection to the backbone for any given period of time.

connection to the backbone can be established. The principal objective of this report is to identify if, and under what conditions standalone hydrogen areas can contribute to the successful roll-out of hydrogen infrastructure in the Netherlands.

This report will first address the following sub-questions based on the direct results from case study research and interviews:

1. **What are the drivers, enablers, and barriers of standalone hydrogen areas?** (3.1 to 3.9)
2. **What are the roles and responsibilities of stakeholders involved in such decentral projects (with a particular focus on those of DSOs and local governments)?** (4.1)
3. **What regulatory requirements are applicable to such areas?** (4.2)
4. **What is the role of such areas in hydrogen infrastructure development?** (4.3)
5. **What are the technical characteristics of hydrogen produced in such areas (in terms of volumes, pressure, and quality)?** (4.4)
6. **What role does e-grid congestion play in such areas and what is their impact on the grid in turn?** (4.5)

The final section of this report will evaluate the potential of standalone hydrogen areas by answering the following sub-questions:

1. **What notable enablers and barriers are identified across case study areas and what does this suggest about necessary criteria for successful standalone regions?** (5.1)
2. **To what degree are standalone hydrogen areas viable solutions based on lessons from case study areas?** (5.2)
3. **What "typologies" of standalone hydrogen areas can be identified based on case study areas?** (5.3)

To answer these questions, 9 diverse case study areas have been identified in the Netherlands that qualify as standalone hydrogen areas under the definition outlined above. For each case study, we employed a combination of semi-structured interviews with stakeholders and desk research to distil generalisable findings that can be used to inform future infrastructure projects. This research aims to shed light on the role that standalone hydrogen areas will play in the roll-out of hydrogen infrastructure and decarbonisation efforts, thus providing much-needed clarity for decentral hydrogen users who will depend on such infrastructure in the near-future.

Box 1. Reading guide for this report

Reading guide

This deliverable provides a lot of information that might be relevant for different types of stakeholders with different interests. With this reading guide we aim to guide the reader to the topics that are of their main interest.

Chapter 2 provides an overview of the methodology and limitations of the research.

Chapter 3 provides detailed information about every selected standalone hydrogen case: description of the project, its unique background story, and its specific drivers, enablers, and barriers. The generalized enablers and barriers are presented in chapter 5.

Chapter 4 is an overview of main considerations for setting up standalone hydrogen areas. These subchapters include the direct results of the case analysis and interviews and represent case-specific perceptions and should be interpreted with this context in mind.

Chapter 5 involves the strategic insights on the potential of standalone hydrogen areas in the Dutch energy transition. Are they viable? What role can they have in the Dutch energy transition? Which types of standalone hydrogen systems might be considered?

Chapter 6 provides the general conclusions of this report and its main research questions.

2. Methodology

In this chapter, the decisions on the research setup are outlined and potential limitations and drawbacks are explained.

2.1 Case study approach

We adopted a case study research model using diverse cases. Standalone hydrogen areas (those in which hydrogen is produced and consumed, with assets owned by at least two distinct parties, which initially will operate without a direct pipeline connection to the backbone) formed our unit of analysis. Adopting a clear, yet intentionally broad, definition of standalone hydrogen areas provided a means of selecting cases that shared the key defining characteristics of standalone hydrogen areas but allowed for variation in other factors (such as their size, intended end-use of hydrogen, or the stakeholders involved). Diverse cases were strategically selected to represent the variation of cases in the population (a list of +/- 40 case options). Contrary to selecting cases that are typical to one another, this case selection methodology can strengthen a researcher's claims of generalisation to the population [7]. The heterogeneity of the cases used in this research aims to represent the variation in standalone hydrogen area typologies in the Netherlands now and in the future.

We selected a case study methodology in lieu of alternative research methods, such as experimental research, for three principal reasons. First, case studies are often regarded as explorative in nature and do not require control over the context in which the unit of analysis is situated [8]. Case study research investigates real-word phenomena within their real-life context. The phenomena (in this case, standalone hydrogen areas) are intrinsically linked to the context in which they are situated (e.g., the regulatory, stakeholder, economic, and environmental conditions). Attempting to separate the phenomena from the context in this case would have been unfeasible, but from a theoretical perspective would have hindered our ability to account for the effect that the respective regulatory, stakeholder, economic, and environmental conditions have on each chosen standalone hydrogen area.

Second, case studies are particularly suitable for scenarios in which there is a limited sample size (which is the case given the comparatively small number of standalone hydrogen areas in the Netherlands at present) with a relatively high number of critical variables [8]. Our main research question asks "under what conditions" standalone hydrogen areas are successful, suggesting an unspecified number of critical explanatory variables that could impact the success of each area. A case study approach allowed us to conduct in-depth exploratory analysis of each of the chosen case study areas to draw out any influential variables and hypothesise about their impact.

Third, case studies are often theoretically (rather than statistically) generalisable to a larger population under certain conditions [9]. In other words, the findings obtained from a select number of case studies can be generalised to other cases which are structurally similar to the studied cases. Rather than enumerating statistical frequencies, which would be challenging given the comparatively small number of standalone hydrogen areas in the Netherlands at present, case study research provides a framework for translating in-depth research from a strategically selected sample group to other applicable populations (in this case, future standalone hydrogen areas).

We translated findings from individual case studies to theoretically generalisable conclusions about other standalone hydrogen areas in the Netherlands now and in the future. Specifically, we identified notable cross-case enablers and barriers; assessed their viability based on key criteria brought to light by case study results; and defined typologies of standalone hydrogen areas in the Netherlands.

2.2 Case selection

The final case study selection process began by identifying a list of projects or initiatives in the Netherlands that fell within the bounds of our definition of standalone hydrogen areas, beginning with projects in the New Energy Coalition (NEC) network and subsequently reviewing public repositories of planned, ongoing, and operational hydrogen projects in the Netherlands [10], [11].

We identified a series of indicators used to gauge each project's relevance to our main research question and, through desk research of project documentation, websites, press releases, and so on, assigned values for each proposed case study. The indicators included: the size of the project (in terms of expected hydrogen production); the source of energy used to produce the hydrogen; the intended end-use sector(s); the planned hydrogen transport method; the direct involvement (or lack thereof) of a DSO; and the relevance of e-grid congestion to the project. We also included certain practical criteria in our decision-making process, namely: whether NEC was directly (or indirectly) involved in the project, which would make obtaining research materials and contacts for interviews more feasible; and the current stage of the project, which allowed us to strategically include advanced projects to highlight the unique perspectives of those that had reached FID or even proceeded to the commissioning and operational stages.

We disqualified case studies that did not exhibit a high degree of relevance to our main research objectives after reviewing the key indicators for each case. Thereafter, we strategically selected a sub-set of cases that constituted a diverse group of projects, which displayed variation across indicators (e.g., size, end-use, and so on) but remained within the bounds of relevance to our research. Special consideration was given to case studies in the advanced stages of development, as well as those that had some level of NEC involvement. The final case study selection is shown in

Project Name	Starting size (electrolyser)	Scale-up size (electrolyser)	Hydrogen transport	Hydrogen end-use	DSO involvement	NEC involved	Project stage	FID
Agriport A7	5 MW	14 MW	Pipeline, tube trailer	Industry, agriculture	Yes	In contact	Detailed design	No

Bolsward	5 MW	25 MW	Pipeline	Industry, mobility possible	No	In contact	Tendering	No
Duwaal	5 MW	Unspecified	Pipeline, iBundle	Mobility	No	Yes	Development	No
GROHW	2.5 MW	30 MW	Pipeline, tube trailer	Industry, mobility	Yes	No	Pilot complete, planning	No
H2 Hollandia	5 MW	-	Tube trailer	Mobility	No	No	Development	No
H2avennet	55 MW	500 MW	Pipeline	Industry, mobility	Yes	No	Detailed design	No
H2GO	2 MW	85 MW (potential cumulative projects)	Pipeline, tube trailer	Mobility, built environment	Yes	No	Planning, realisation (varies by project)	Yes (Greenpoint), No (other projects)
Hessenpoort	0.85 MW	15 MW	Tube trailer	Mobility, wastewater treatment	No	No	Realisation	Yes
Zephyros	2 MW	200 MW	Tube trailer, pipeline possible	Mobility	No	Yes	Planning	No

Table 1.

Table 1. Final list of hydrogen standalone area case studies.

Project Name	Starting size (electrolyser)	Scale-up size (electrolyser)	Hydrogen transport	Hydrogen end-use	DSO involvement	NEC involved	Project stage	FID
Agriport A7	5 MW	14 MW	Pipeline, tube trailer	Industry, agriculture	Yes	In contact	Detailed design	No
Bolsward	5 MW	25 MW	Pipeline	Industry, mobility possible	No	In contact	Tendering	No
Duwaal	5 MW	Unspecified	Pipeline, iBundle	Mobility	No	Yes	Development	No
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H2GO	2 MW	85 MW (potential cumulative projects)	Pipeline, tube trailer	Mobility, built environment	Yes	No	Planning, realisation (varies by project)	Yes (Greenpoint), No (other projects)
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Zephyros	2 MW	200 MW	Tube trailer, pipeline possible	Mobility	No	Yes	Planning	No

2.3 Semi-structure interview design and execution

For each case study we conducted semi-structured interviews with key stakeholders to obtain a more nuanced perspective of each standalone hydrogen area, beyond what desk research alone would yield. Qualitative research interviews can be designed with varying degrees of structure. We chose what is commonly referred to as a "semi-structured" interview format, as it provides a thematic, topic-centred structure, while allowing for flexibility and a conversational-style of dialogue [12]. This interview format consists of a series of important topics or themes that the interviewer would like to cover, rather than a strict list of questions that would be asked systematically to all participants before making analytical comparisons of responses. This sort of "structured" interview, which could be accomplished with merely a survey-list of questions, would better suit research with a large sample group and relative homogeneity between the contexts of each case study.

Given our comparatively small sample size of nine case studies, each with a unique context, it was important that we chose an interview structure that allowed us to adapt our questions and steer our conversations differently depending on the individual situation and the perspective of the interviewee. Such flexibility also kept the door open for exploring emerging insights that might not have been an initial focus but showed relevance, nonetheless.

The design of the semi-structured interviews began by outlining the main and sub-research questions that we intended to answer in our research. We then identified possible interview questions and applicable follow-ups that could be posed to interviewees to prompt relevant responses before cross-referencing them back to our principal research aims to ensure continuity, following the framework shown in Figure 3.

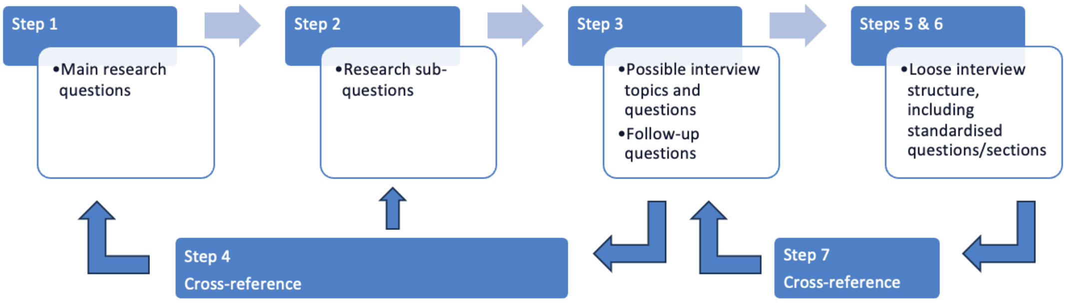

Figure 3. Semi-structured interview question design. Adapted from [11].

Using the list of possible interview questions, we designed a logical structure that followed a natural flow of broad questions becoming progressively more specific. Finally, we cross-referenced the final interview structure and questions with our initial research objectives to ensure they would yield relevant results.

Before conducting interviews, we identified points of contact at each of the case study areas and conducted informal meetings to provide the necessary background information of our report and how it is situated in the broader HyDelta3 research. From each of these points of contact, we were able to identify the most relevant stakeholders and additional contacts that would be able to provide answers to the interview questions we had designed. After scheduling interviews with all relevant contacts that had agreed to participate in our research, we briefly adapted our interview questions and structure to ensure that focus was placed on thematic areas most relevant to the respective interviewee's knowledge and expertise. The eventual interviews were conducted virtually with two members of our research team, then recorded, transcribed, and coded to identify pervading themes and insights across case study areas. A list of the 20 interviews conducted can be seen in Table 2.

Table 2. List of stakeholder interviews with relevant project, company/organisation, and job title (if relevant).

Relevant Case Study Area	Company or Organisation	Title (if relevant)
Agriport A7	ECW	Customer & Market Manager
Agriport A7	Datacentre off-taker	
Bolsward	Gemeente Súdwest-Fryslân	Program Manager
Bolsward	Private Consultancy	
Duwaal	HYGRO	Program Coordinator
Duwaal	Soluforce (pipeline supplier)	
Duwaal	AVIA Marees	Financial Controller
GROHW	Witteveen+Bos	
GROHW	Communications Advisor	
H2 Hollandia	Repowered	Project Manager
H2avennet	Port of Amsterdam	
H2avennet	DEP	Project Manager
H2avennet	Firan	
H2GO	Private Consultancy	Program Manager
H2GO	(Former) Equipment Supplier	
H2GO (Stad Aardgasvrij)	Stedin	
H2GO (Stad Aardgasvrij)	Essent	Business Developer
Hessenpoort	Province Overijssel	Director Smart Energy Hub Regio Zwolle Noord
Zephyros	Port of Den Helder	Deputy Director
Zephyros	H2 Marine Solutions	

2.4 Limitations of research setup

The qualitative method was selected due to its explorative nature and relevance to a diverse set of standalone hydrogen area cases. To evaluate the viability of the cases, a quantitative economic assessment could be expected. However, this was not included in part due to limited timeframe. Moreover, previous research suggests most hydrogen-related business cases are not economically viable without public support yet. Therefore, focus was placed on learning how the selected case study areas are navigating such challenges rather than on a large economic assessment of standalone hydrogen areas now and in the (far) future. Nevertheless, future work may consist of a cost-benefit analysis of the selected 9 pilot areas, which may lead to different conclusions regarding the viability of these standalone hydrogen projects.

The bulk of information used in this research was sourced from interviews with experts and stakeholders involved in the selected standalone hydrogen areas. We acknowledge that expressions of these stakeholders might be biased by their perspective and personal opinions. In our process of analysis, we clearly differentiate between the established fact-based project characteristics and information that represents a perception of a stakeholder based on experiences and opinions.

It is also important to note the dynamic nature of the case study areas given they are in various stages of development and subject to change at any given time. The analysis in this report is based on information obtained from the projects at the time of writing, which is understandably expected to change as they progress. It remains to be seen if and how these projects will continue to develop. More can be learned about the potential for such standalone areas in the future when more projects have reached maturity.

3. Case study areas: background, drivers, enablers, and barriers

Every standalone hydrogen case that was selected for this study was found to have a unique story behind its developments and decisions. In this chapter we will highlight these unique backgrounds, principal drivers, enablers, and barriers for the nine investigated projects.

Figure 4. HNS backbone approximated from [1], [13], [14]. Case Study Locations: Agriport A7 (5 to 10 MW, datacentres); Bolsward (5 to 25 MW, industry); Duwaal (5 MW, mobility); H2 Hollandia (5 MW, mobility); H2avennet (55 to 500 MW, industry); H2GO (2 to 85 MW, built environment and mobility); Hessenpoort (0.85 to 15 MW, mobility and WWTP); Zephyros (2 to 200 MW, mobility)

Box 2. Readers tip on efficiently obtaining the information of interest from chapters 3, 4 and 5.

Reader's tip

Because nine standalone hydrogen cases were investigated, each with a unique history and set of characteristics that are worthwhile mentioning to fully understand the analysis and conclusions, this chapter contains +/- 29 pages. This chapter describes nine unique stories on how a standalone hydrogen project could start and what opportunities and barriers are faced when developing such a project. <u>For readers that are only interested in cross-case insights, we recommend skipping to chapter 4.</u> For readers who are only interested in the more high-over and strategic insights on the role and viability of standalone hydrogen areas in the Dutch energy transition, we recommend skipping to chapter 5.

3.1 Agriport A7

Box 3. Fast facts Agriport A7.

Location: Middenmeer, Noord-Holland
Starting size (electrolyser): 5 MW
Scale-up size (electrolyser): 10 MW
End-use: Zero emission backup power for datacentres
Other details: Waste heat utilised for greenhouse horticulture, possible future transition to hydrogen

Background

The project at Agriport A7 – a business park area along the A7 near Middenmeer, home to datacentres, greenhouse horticulture, among other business activity – originated from local datacentres needing an alternative to conventional diesel generators for backup power. Further expansion in the Netherlands is not possible unless a sustainable alternative, such as hydrogen fuel cell backup (although now combustion in CHPs is also being considered), is implemented. A secondary objective to the project is helping to decarbonise datacentres' energy supply by utilising hydrogen to work towards 24/7 matching of renewable energy supply with their consumption. Waste heat from hydrogen production will be harnessed for use by local greenhouses, and a further scale-up phase would involve the development of a hydrogen ecosystem in Agriport A7, in which hydrogen is used as fuel in CHPs.

ECW is the private DSO utility company for energy (gas, power, heat, CO2), water and fibre in the Agriport A7 area who will likely be investing in the hydrogen infrastructure and is a key partner in the project. A feasibility study completed in 2023 recommended a maximum of 14 MW of electrolyser capacity and 10 tons of storage. According to ECW, a phased approach starting from 5 MW of electrolyser capacity will be a likely starting point, with the potential scale up to 14 MW.

Achieving full-scale backup from the datacentres and the plans for developing a broader hydrogen ecosystem are completely reliant on receiving an HNS connection, since local production could not feasibly produce the volumes of hydrogen required at this scale, ensure reliability of supply, and come at a cost low-enough to facilitate a transition in the greenhouse economy where price is the principal concern. Agriport A7 is situated along the planned backbone and talks are ongoing, however the timeline for connection remains unclear. The project will now move into a detailed design phase, in which the datacentres will explore these options in more technical detail and will ultimately decide whether to invest in the project, which ECW asserts will either be the biggest enabler of the standalone project or will be the "*showstopper*."

Drivers, enablers, and barriers

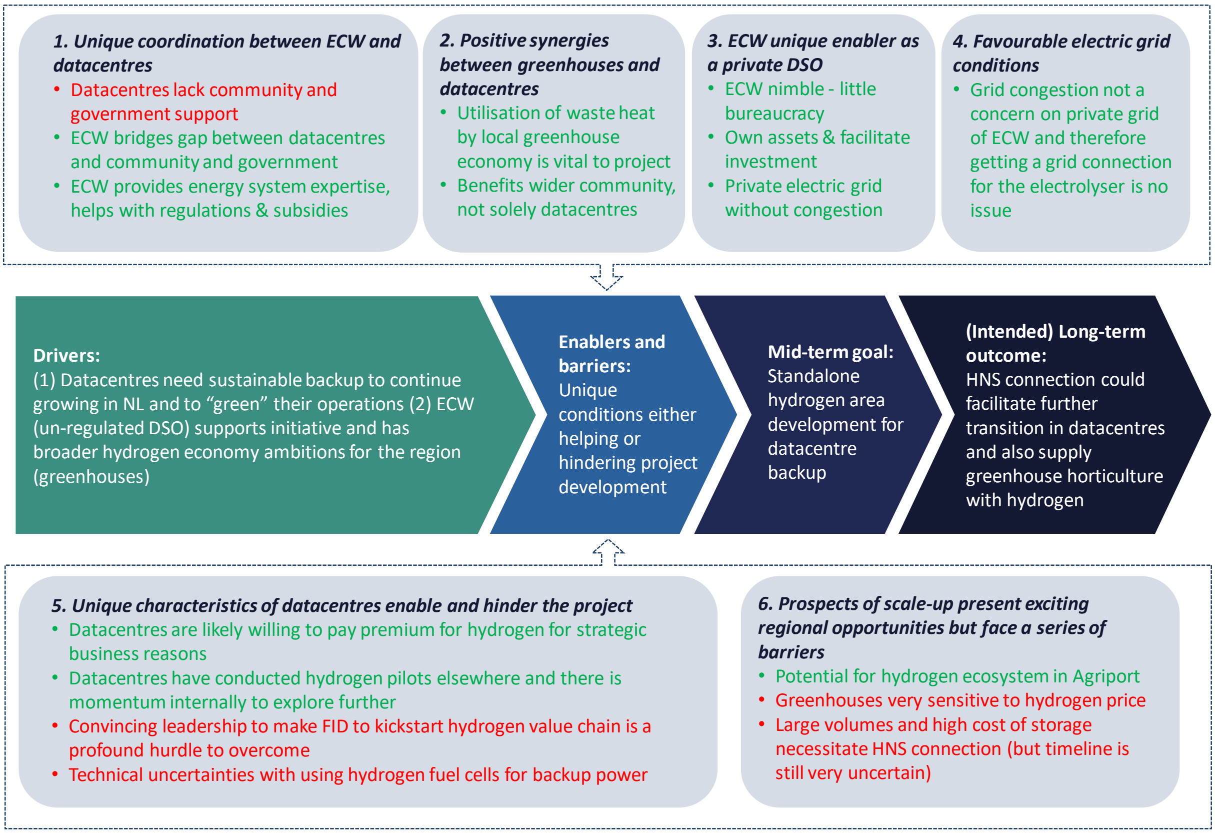

Figure 5. Agriport A7: Drivers, Enablers (green), Barriers (red).

The main drivers of this project are the interest of the datacentre off-taker and the ambition of the local private DSO, ECW. For the datacentres, this project is a strategic opportunity to test the feasibility of using hydrogen for backup, enter the hydrogen market, and kickstart the local hydrogen economy to eventually earn an HNS connection. The side benefit of using hydrogen to work towards 24/7 matched renewable production with their consumption has intrinsic benefits of green imaging.

ECW is motivated to provide sustainable solutions for their customers including datacentres. Further, the utilisation of waste heat and the potential hydrogen demand from the greenhouse CHPs, suggests that hydrogen infrastructure investments by ECW would benefit the broader economy, not the datacentres alone.

There is uncertainty about the timeline of the HNS connection and the feeling from ECW that this area is not a priority. There is further uncertainty of whether the backbone will provide 100% green hydrogen in the earliest stages and the datacentre off-taker is very interested in ensuring green hydrogen to get the side benefit of greening their image and achieving 100% renewable off-set, which (coupled with the uncertainty of the backbone connection) strengthens the argument for a standalone area.

The following conditions outline unique characteristics, other than the underlying drivers mentioned above, that are enabling or hindering this project: The following conditions outline unique characteristics, other than the underlying drivers mentioned above, that are enabling or hindering this project:

1. Unique coordination between ECW (private DSO) and datacentres enable the project

Enabler: There is close coordination between the datacentres and ECW. ECW brings expertise in the energy system, familiarity with government regulations and potential subsidies, and general coordination capacity to the table.
Barrier: It is expected that local government will be hesitant to support the project if it only benefits datacentres rather than the wider community. The datacentres are perceived to be closed off from the local area and earning community and government support for such a project could be a challenge.
Barrier: There is also a (false) perception that electricity from large wind farms nearby already takes care of decarbonising the datacentres, so there is little need for new initiatives.
Enabler: It is expected that ECW can help to bridge the gap between the datacentres and the local community and government and navigate these expected challenges.

2. Positive synergies between greenhouses and datacentres (waste heat and backup power)

Enabler: The utilisation of waste heat to benefit the greenhouse economy is perceived to be critical to the success of the project, largely by fostering a sense that this project will benefit the wider community, not solely the datacentres.
Enabler: There is the possibility of further synergy between greenhouses and datacentres, by utilising CHPs as an additional source of backup power for the datacentres, in conjunction with hydrogen: *"In the early stages … you could have both [hydrogen and CHP backup] which would help because our business is very risk averse. So, this would really help that you always have that trusted and known backup supply on natural gas" (datacentre off-taker).*

3. ECW is a unique enabler as a private DSO

Enabler: ECW is perceived to be more nimble than a strictly regulated public DSO. They have the capacity to work closely with the datacentres and assist with the development of the project. They are perceived more flexible with being able to invest and own their own assets and to facilitate investment, and they can be quick to formalise contracts and move the project along because of a lack of bureaucracy.

4. Favourable electric grid conditions enable the project

Enabler: Grid congestion is less of a concern on the private grid of ECW and therefore getting a grid connection for the electrolyser is easier. Available and required power are scheduled and projects are executed at an integral level within the business park.

5. Unique characteristics of launching off-taker enable and hinder the project

Enabler: For strategic business reasons, the datacentres are likely willing to pay more for hydrogen than the greenhouse off-takers in the area, which is needed to kickstart the infrastructure investments. The datacentres have also already conducted hydrogen pilots and are confident in the role that it could potentially play and there is momentum internally to explore hydrogen.
Barrier: Regardless, securing leadership approval and reaching FID before any infrastructure is developed is a challenge posing an existential threat to the project.
Barrier: Using hydrogen for backup power alone is a very poor business case due to the low electrolyser running hours. Nonetheless, this can be mitigated by using hydrogen for matching renewable production with consumption, thereby increasing the electrolyser utilisation.

Barrier: There are also technical concerns about the efficiency and reliability of using hydrogen fuel cells for backup purposes. Moreover, hydrogen purity will be an issue if used in a fuel cell and if hydrogen is eventually supplied from the backbone in later scale-up stages, it will lead to higher costs from purification. For both reasons, using hydrogen in CHPs is being considered as an alternative to fuel cells.

6. Prospects of scale-up present exciting regional opportunities but face a series of barriers

Enabler: There is large potential to use hydrogen in CHPs in the local greenhouse economy, suggesting a wider hydrogen economy could be developed.
Barrier: Unlike the datacentres, the greenhouses do not have any reason to pay more for hydrogen than they do for natural gas (until 2040, when requirements for decarbonisation kick in). Further, standalone production would not be feasible due to the large volumes and low price demanded by greenhouses, coupled with the high cost and regulatory challenges of large-scale storage. Thus, this stage hinges on obtaining an HNS connection, the timing of which remains unclear. *"That whole timeline [of connection to HNS], that's the greatest barrier, I guess … We also spoke with HyNetwork for a CSA. They said, 'There is no problem, we're going to do that together.' And now they say, 'We just have to focus on the first 5 clusters' … and then after that they're going to look at the sixth cluster … So we're feeling we're a bit at the end of the line" (ECW).*

3.2 Bolsward

Box 4. Fast facts Bolsward.

Location: Bolsward, Súdwest-Fryslân
Starting size (electrolyser): 5 MW
Scale-up size (electrolyser): 25 MW
End-use: Industry, possibly mobility
Other details: Waste heat and oxygen utilisation potential

Background

The Bolsward project is a bottom-up initiative originally stemming from the intention to utilise waste heat from four local industry partners in the city's district heating system. Early in the process, industry partners expressed interest in using green hydrogen to offset their natural gas consumption. The hydrogen project is driven by the municipal government and with ambitions to scale up to 25 MW of electrolyser capacity and 5 tons of storage (based on the current natural gas demand from local industry). Other industry and mobility off-takers in a 50km radius of Bolsward are also being considered. Waste heat from hydrogen production and industry processes will be used for district heating and waste oxygen will likely be used in wastewater treatments processes.

According to the project manager, who is employed by Gemeente Súdwest-Fryslân, the project will adopt a phased approach, beginning with 5 MW of electrolyser capacity by 2028 and scaling up to full capacity within three years. Green electricity will be purchased from Wind Park Fryslân (WPF) with a 25 MW connection for the electrolyser to a new Liander substation expected by 2026. The industry off-takers are expected to use a mix of hydrogen and natural gas in their processes in early stages when hydrogen is produced locally. However, it is expected that a backbone connection would be needed to facilitate a 100% transition to hydrogen from a reliability of supply standpoint. There are no agreements yet from off-takers, but it is hoped FIDs will be reached by 2026. The project is currently wrapping up a market consultation phase and moving into the tendering process.

Drivers, enablers, and barriers

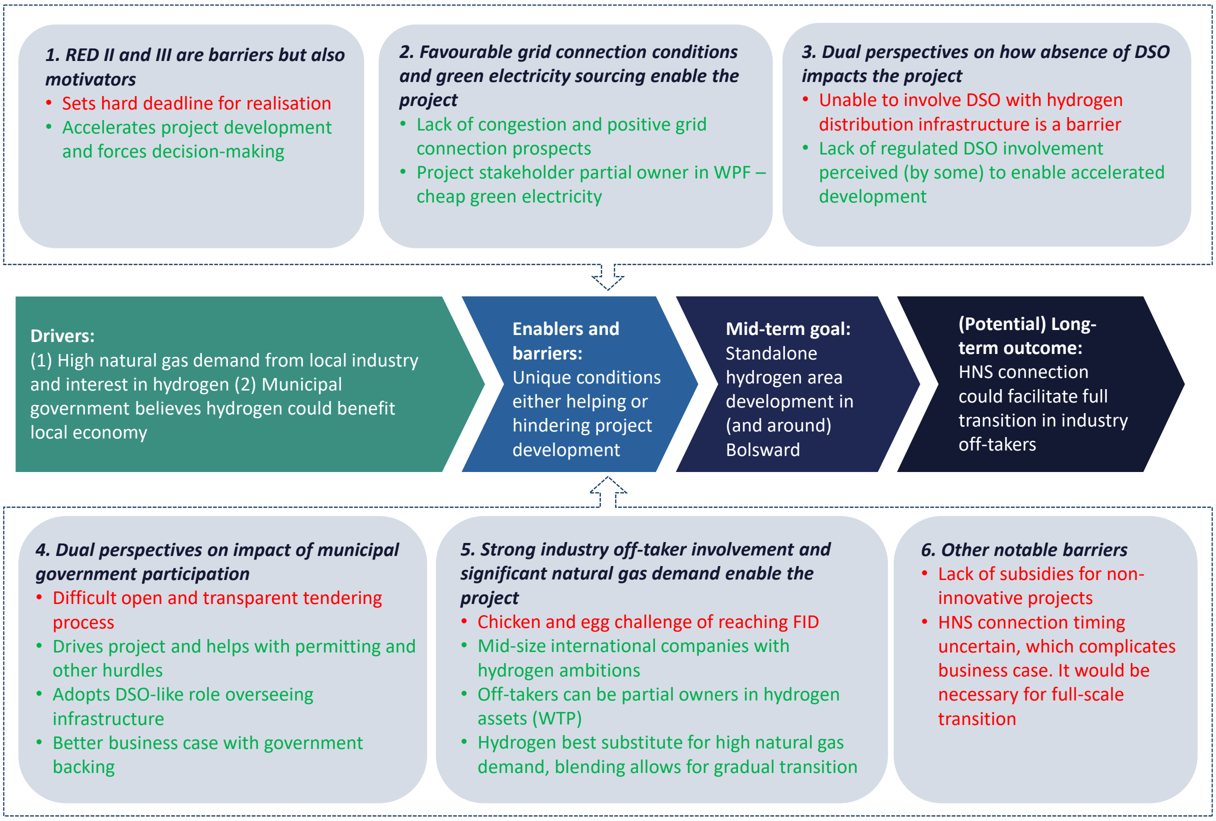

Figure 6. Bolsward: Drivers, Enablers (green), Barriers (red).

There is a perception that the backbone connection timeline is uncertain, and the process is not as transparent as it once was. This uncertainty, combined with the high costs of an HNS connection, strengthen the argument for local production and standalone operation in early stages.

The following conditions outline unique characteristics, other than the underlying drivers mentioned above, that are enabling or hindering this project:

1. RED delegated act (particularly additionality principle) is a barrier but also a motivator

Barrier: The additionality requirement from the delegated act is cited as a major barrier to the project as there is a hard deadline for realisation before 2028 to qualify for the relevant exception.[2]
Enabler: However, the European regulations serve as a strong motivator by forcing decisions to be made now that otherwise would likely take time. For example, the project must apply for a grid connection for an electrolyser based on the anticipated size of the project in its later stages without having any firm financial commitments from off-takers, simply to ensure that the connection is realised in time. Although those involved with the project expressed a desire for an extension to the exception to the additionality principle in the delegated act, it was acknowledged that having such a firm deadline

[2] Further information on the *Delegated Act on a methodology for renewable fuels on non-biological origin*, which sets guidelines for defining renewable hydrogen can be found here [15].

keeps the project moving along, especially one led by a municipal government which could be at risk of stalling. *Because the delegated act of RED III specifies an additionality requirement for electrolysers that applies from 2028 onwards, the project aims to be realised before that year. On the one hand, it is good to be pushed to go fast. However, it is really complicated to develop many things at the same time while they are partially interdependent. Therefore, it would have been easier for us if that legal requirement started later. " (Project Manager Bolsward)*.

2. Favourable grid connection conditions and green electricity sourcing enable the project

Enabler: A good relationship with Liander and frequent communication instils confidence that the grid connection for the electrolyser will not be an issue. Nonetheless, Bolsward is still subject to Liander's slow and bureaucratic process.
Enabler: There is a unique relationship between the owners of WPF and stakeholders in the project, one that Bolsward expects to benefit from in seeking a competitive price of renewable electricity.

3. Dual perspectives on how lack of DSO involvement impacts the project

Barrier: Despite coordination with Liander on the electric grid connection, there has not been any involvement of a DSO in the hydrogen infrastructure. Involving Firan, a commercial subsidiary of Alliander, in the project is perceived by the project manager to be advantageous, but due to Firan's involvement with other hydrogen pilots, there is little appetite to enter the Bolsward project.
Enabler: On the other hand, a technical consultant on the project perceives the involvement of a regulated DSO in the distribution infrastructure to be a barrier and would slow the process down. Instead, the municipality plans to oversee the regional hydrogen distribution infrastructure, treating it as a public good, and will tender its development to private parties.

4. Dual perspectives on the impact of strong participation from the municipal government

Enabler: There is a perception that having the local government closely involved and engaged will help accelerate permitting stumbling blocks.
Enabler: There is a perception that having the local government closely involved and engaged will help accelerate permitting stumbling blocks.
Enabler: Further, the business case for infrastructure investments is stronger with municipal backing and CAPEX costs can be stretched over 50 years rather than shorter periods in other projects.
Barrier: Nonetheless, not showing preference to certain market parties and maintaining an open and transparent tendering process is perceived to be a challenge.
Barrier: Despite strong support at the municipal level, the province is hesitant to devote too many resources to a project largely focused on industry, for fear of snubbing the agricultural sector in the region. While not needed at this stage of the project, the project manager acknowledged that earning provincial support will be key in the future.

5. Strong industry off-taker involvement and significant natural gas demand enable the project

Enabler: The municipal government engaged with four industry off-takers early in the process coordinated the signing of a letter of intent (LOI). Proactive outreach by program management was perceived to be an enabler. For example, off-takers were brought to DNV to demonstrate dual fuel burners and increase familiarity and support. The prospects of achieving FIDs with at least two off-takers are very good according to the project manager.

Enabler: Unique characteristics of the off-takers are perceived to be favourable: many are medium-sized, international companies, aware of future EU ETS guidelines and its impact on CO_2 prices, that are willing and able to take steps towards decarbonisation (maybe more so than local SMEs).
Enabler: Off-takers have the opportunity to be partial owners in their energy supply assets, so it is a strategic investment that is perceived by one stakeholder in the project to lead to a higher willingness to pay.
Enabler: Further, off-takers consume large volumes of natural gas. In many cases, alternatives, such as electrification or biogas, are not suitable for their processes, thus strengthening the push for hydrogen. Blending hydrogen with natural gas in early stages would allow companies to transition slowly and make stepwise investments, which are more feasible than targeting 100% decarbonisation in one-go.
Barrier: Despite confidence in the prospects of signing off-taker agreements, reaching FID before infrastructure is developed (all ahead of the 2028 deadline for the additionality exception) is still perceived by both interviewees to be one of, if not the most significant, hurdle to be overcome. While certain off-takers are likely to proceed, others are hesitant because electrification happens to be a valid alternative to consider, they have concerns about the hydrogen price, or they are simply too small compared to the larger international companies.

6. Other notable barriers

Barrier: Finding relevant subsidies is perceived by the project manager to be a challenge, as applicable EU, national, and provincial subsidies are geared towards innovative solutions, while the Bolsward project employs a standard approach to hydrogen production, transport, and consumption.
Barrier: Gasunie was involved early in the project to share knowledge and learnings, which was perceived as an enabler. But now, the perception has changed in that the HNS connection process and timeline is opaque. A clear and reliable timeline could help the business case (e.g., knowing that less storage will be needed).

3.3 Duwaal

Box 5. Fast facts Duwaal.

Location: Wieringerwerf and throughout Noord-Holland **Starting size (electrolyser):** 5 MW **Scale-up size (electrolyser):** Unspecified **End-use:** Mobility **Other details:** 5km composite pipeline (40 bar) to “hub” then iBundle storage and transport method

Background

The Duwaal project is owned and operated by HYGRO. The project will begin with a 5 MW electrolyser co-located with the 4 MW HYGRO wind turbine in the Wieringerwerf. The plan is to transport the green hydrogen via a privately-owned 5km composite high-pressure (40 bar) Soluforce pipeline to an AVIA Marees fuelling station. This point will serve as a filling station and hub for then distributing the hydrogen using unique iBundles (storage units where hydrogen is compressed to 1000 bar and shipped in modular containers sized 1.2m x 1.2m x 2.7m) to a series of satellite stations throughout Noord-Holland, with the main goal of serving the mobility sector.

The opportunity to scale the project is by means of replicating this model in other projects. However, it is also expected that as more wind turbine manufacturers explore direct electrolysis from wind, the current site could be expanded as a testing ground, allowing more electrolysis and greater hydrogen capacity into the planned pipeline, given that the pipeline is vastly over-sized compared to the current 5 MW of production.

Conversations between HYGRO and mobility off-takers are ongoing, but contracts are not yet finalised. There is a long-term goal to make a connection to supply the backbone with 10 to 15 years.

Drivers, enablers, and barriers

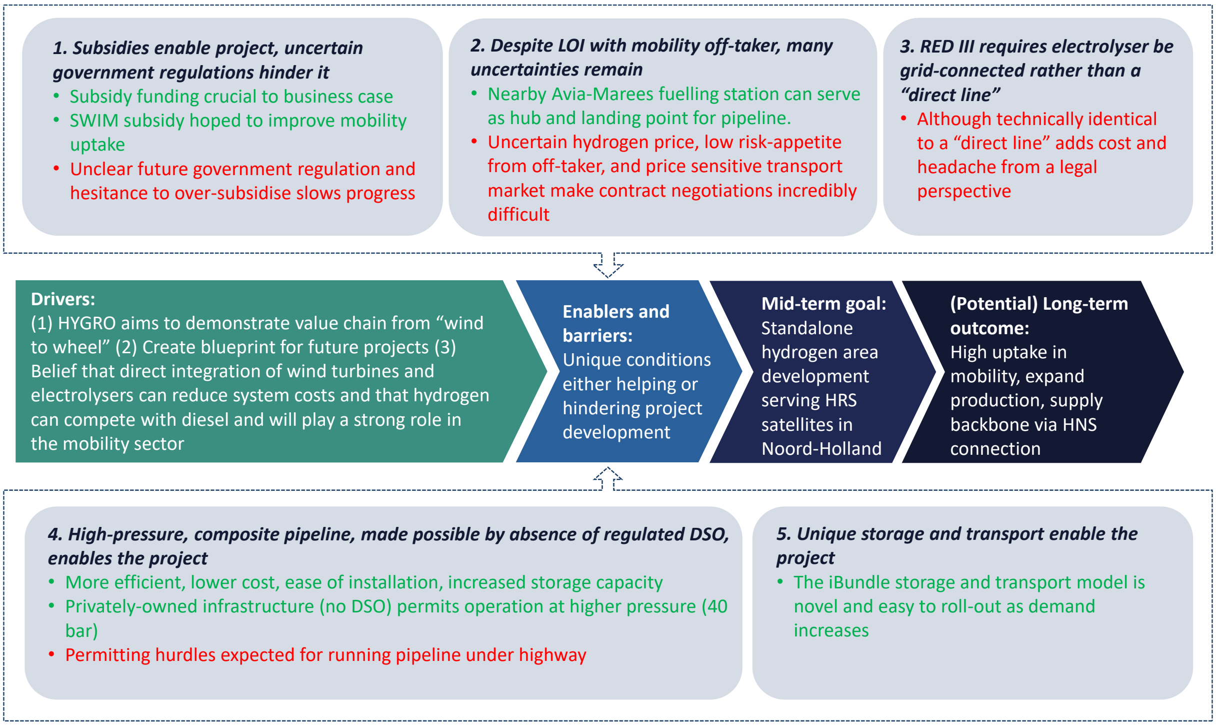

Figure 7. Duwaal: Drivers, Enablers (green), Barriers (red).

HYGRO is the principal driver of the Duwaal project. A set of underlying principles within HYGRO shed light on the drivers of this project, namely: the conviction that hydrogen will be the primary energy carrier in the Netherlands; that direct integration of wind turbines and electrolysers and utilisation of composite pipelines can result in significant cost reductions throughout the value chain; and that hydrogen will be highly competitive with diesel and will play a strong role in the mobility sector if it is rolled out in accordance with HYGRO's vision.

The motivation of the project is to demonstrate the value chain from wind to wheel and serve as a blueprint for future projects. The learning aspect of this project is a key driver, with less focus on economic viability in the first phase. However, the latter is expected to improve as supply increases from testing, demand increases from anticipated uptake in mobility, and particularly if connection with backbone can be realised.

The following conditions outline unique characteristics, other than the underlying drivers mentioned above, that are enabling or hindering this project:

1. Subsidies enable the project, while uncertain government regulations hinder it

Enabler: Financial support from the RVO and GroenvermogenNL is a critical enabler of the project, since there is no business case at this small scale without such subsidies.
Enabler: The SWIM subsidy is hoped to improve off-take in mobility by incentivising investment in both filling stations and hydrogen vehicles.
Barrier: Nonetheless, there is a perception that the government is incredibly hesitant to not over-subsidise hydrogen in the mobility sector. There is lack of clarity regarding how future government regulations and subsidy schemes will impact hydrogen price, making the business case very difficult. It is difficult to attract investment if, for example, a potential hydrogen tax in the future could ruin the business case. Hence lack of clarity in future government regulation is a key barrier.

2. Despite LOI with mobility off-taker, uncertainty of hydrogen's role in the mobility sector and its future price needs to be overcome for full buy-in

Enabler: There is a fuelling station relatively close to the electrolyser, which makes it a suitable position for landing the high-pressure pipeline and serving as a distribution hub. An LOI between HYGRO and AVIA Marees suggests that this potential collaboration is an enabler.
Barrier: However, there are differences in opinion regarding the role that hydrogen will play in the mobility sector. Despite HYGRO's conviction that hydrogen will be competitive with diesel in the future, AVIA Marees's "risk appetite" for hydrogen is low given the present lack of demand (which the SWIM subsidy of course hopes to address). AVIA Marees expressed further uncertainty regarding the role gaseous hydrogen would play in the mobility sector compared to electrification, liquid hydrogen, or other biofuels.
Enabler: AVIA Marees would like to establish volume-based contracts with HYGRO, such that HYGRO would pay a fee for using their location as a hub and then also compensate AVIA Marees based on the volume of hydrogen that is sold. One perspective from AVIA Marees is that this type of contract is an enabler and mutually beneficial for producer and consumer. Such contracts allow for the sharing of both risks and benefits between HYGRO and AVIA Marees. If sales happen to be low, variable costs for HYGRO and earnings for AVIA Marees will both be low, while if sales are high, AVIA Marees and HYGRO will both reap the benefits.
Barrier: The perception that hydrogen is meant only for industry and not for mobility needs to be overcome. HYGRO asserts that although the Dutch government is prioritising hydrogen in industry over mobility, using it in this way does not yield the highest value that could be realised.[3]
Barrier: AVIA Marees and HYGRO both acknowledge that the transport sector operates on very slim margins, so the price of hydrogen (relative to diesel) is critical. Until it is cheaper, uptake is not probable. For this project especially, the cost of hydrogen is expected to be higher in the early stages due to the high costs of the pipeline, which is far over-sized and impacts the end cost of hydrogen.
Barrier: Finally, without clarity on the exact hydrogen price (which is largely unclear due to the lack of clarity regarding hydrogen tax and the heavy-duty tax), off-taker contracts between AVIA Marees and HYGRO are difficult to finalise.

3. RED delegated act adds headache by requiring electrolyser be grid-connected rather than a "direct line"

[3] See HYGRO's publication "Double the energy from wind, with hydrogen as primary energy carrier" for more information [16].

Barrier: Due to the 36-month time limit imposed by the delegated act, HYGRO will be forced to connect their electrolyser to the grid, rather than directly to the turbine (at least on paper). Such a setup, although technically identical to the alternative, adds cost and headache from a legal perspective.

4. High-pressure, composite pipeline, made possible by absence of public DSO, enables the project

Enabler: Using a high-pressure composite pipe reduces cost and is more efficient than low-pressure transport. The composite piping is also flexible for ease of installation, and it can handle pressure differences much better than steel piping (which allows for some degree of flexibility provision, but storage is still needed elsewhere in the system).
Enabler: Keeping the pipeline infrastructure privately owned rather than operated by a public DSO permits HYGRO to operate at 40 bar or higher without regulatory restrictions. However, HYGRO would welcome the involvement of a DSO in their project but only if they are willing to operate at pressures above 16 bar. They do not foresee a connection with a low-pressure regional distribution grid and instead will pursue a direct high-pressure connection with HNS in the future.
Barrier: The high-pressure composite pipeline will run under a highway, which, given its novelty, is expected to run into permitting and regulatory hurdles.

5. Unique storage and transport enable the project enable the project

Enabler: The iBundle storage and transport model utilised by HYGRO is perceived to be a very novel solution for the mobility sector by AVIA Marees. Despite their uncertainty regarding hydrogen's role in mobility, they are confident that this type of solution is cheaper than other HRS models and can be rolled out very quickly when demand picks up.

3.4 GROHW

Box 6. Fast facts GROHW.

Location: Deventer, Overijssel **Starting size (electrolyser):** 2.5 MW **Scale-up size (electrolyser):** 30 MW **End-use:** Industry, mobility **Other details:** Waste heat and oxygen utilisation potential

Background

The GROHW project (Green Oxygen, Hydrogen, and Waste heat) largely originated from a consortium of local companies and institutions coordinated by Witteveen+Bos to develop a strategy to advance the energy transition in Deventer with hydrogen as a focal point. A subsidy was secured to fund a 50 kW hydrogen pilot demonstration project in Deventer, which concluded at the end of 2023. For the commercial phase of the project, Witteveen+Bos will be involved in design, safety, and environmental studies; Firan will handle the hydrogen distribution infrastructure, and Essent will be a key investor in the hydrogen production and handle the contracts with off-takers.

The original ambition of the project was to start with 5 MW and scale up to 30 MW of hydrogen production capacity to supply local industry demand and some mobility demand, while making use of waste heat and oxygen. However, due to severe grid congestion, the electric connection cannot be obtained. Instead, the initial phase will likely involve a 2.5 MW electrolyser at Nefit Bosch, an industrial off-taker with an existing demand for hydrogen as a testing laboratory for hydrogen heating systems for the English, Dutch, and German markets. Further, they have available grid connection capacity, thus enabling the first electrolyser phase to be initiated with enough capacity expected to supply two other nearby industry off-takers via pipeline who have existing natural gas demand and can make use of oxygen, while waste heat could eventually be used in the built environment. There is also the potential to serve hydrogen demand for long range transport, as Vos Transport will convert at least one truck to hydrogen that drives to Austria to be refuelled in Deventer.

Further scale up of production capacity is largely dependent on when more electric grid capacity is available in the area, which is not expected before 2030. Contract negotiations between supplier and off-takers are ongoing and expected to be finalised this year, after which point permits will need to be obtained, with realisation of the first 2.5 MW phase anticipated to begin in 2026.

Drivers, enablers, and barriers

Figure 8. GROHW: Drivers, Enablers (green), Barriers (red).

Witteveen+Bos and local industry were key drivers in the early stages of the GROHW project. Witteveen+Bos was motivated to participate in a hydrogen project given the prominent role they expected it to play in the energy transition and therefore took a leading role in building the consortium, securing subsidy funding, and realising the pilot stage, which helped to propel the project into its current commercial phase.

Since industry demand in Deventer remains too small now to get an HNS connection, Witteveen+Bos perceived a standalone project could help to scale up demand to eventually warrant a backbone connection, thereby guaranteeing a reliable hydrogen supply for local industry to fully convert their processes. Furthermore, Firan is also advocating for the realisation of a backbone connection, and they are a key partner in the project and thus a driver of what is to come.

The following conditions outline unique characteristics, other than the underlying drivers mentioned above, that are enabling or hindering this project:

1. Presence of hydrogen, oxygen, and heat demand from industry enables the project enables the project

Enabler: Nefit Bosch is a key kickstarting customer with an existing hydrogen demand. Moreover, their size and market reach is perceived to be a huge motivator. Having such a company in the area with the potential demand for large volumes of hydrogen motivates the project managers to figure out the rest of the supply chain.
Enabler: There are other potential off-takers (e.g., Nefit Industrial) located nearby that also have demand for hydrogen and are willing to start to switch some of their processes over but can use natural gas as a backup. Nefit Industrial also presents an opportunity to utilise waste oxygen in their process (and having such synergies is perceived to be a success factor for these types of projects by Witteveen+Bos). Thus, the geographic concentration of these off-takers makes it possible for Firan to invest in pipeline transport between them and make oxygen usage feasible, whereas this would not be the case if distances were further.
Enabler: Aside from having launching customers, there is potential to scale this project much larger by simultaneously increasing hydrogen usage from the launching customers and connecting other industry off-takers in the region. Firan sees the capacity of this network at 100 MW and has ambitions to connect to the backbone. This vision, from more than one party, to expand the network far and beyond its initial scale, is a key unique enabler.
Enabler: Witteveen+Bos feels that companies might be willing to pay a bit more because of the early stage scale up nature of the program. Moreover, subsidy funding helps with costs throughout the value chain, and the fact that the launching off-takers are close to one another means the costs of hydrogen can remain fairly low in the early stages. It is perceived that even if off-takers are only willing to pay a bit more because it is a pilot, it is important to start now and get a foot in the door to build acceptance with people working with the equipment ("*boots on the ground*").
Barrier: One challenge will be providing reliability to Nefit Bosch, which requires pure hydrogen and cannot blend. Although tube trailers will be utilised to provide some buffer, scaling to much larger volumes will require a backbone connection. Fortunately, Nefit Industrial will have the flexibility to use natural gas whenever needed in the early stages.
Barrier: Another unique barrier is determining what odorant will be used in the regional grid and where it will be added, as Nefit Bosch needs to test the odorant used in the UK, which could be different than what is used in the Netherlands. Therefore, the placement of purification equipment before use in mobility off-take is an ongoing discussion.

2. Key enabling partners: Witteveen+Bos finds investing company (Essent), Firan brings expertise for transport, Municipality of Deventer helps with stakeholder management, Oost NL helps with further subsidy funding

Enabler: Finding a key investing company like Essent is also perceived to be a critical enabler of the project. Essent, like the ambitions of Witteveen+Bos and Firan, has a directive from their parent company to develop hydrogen facilities of a small to medium scale in the Netherlands. Therefore, they are willing to take somewhat of a risk on this project. There is a unique setup where Essent will only pay Witteveen+Bos once the project is successful, so Witteveen+Bos is absorbing much of that risk itself. Having companies that are not risk averse and are committed to hydrogen projects at a higher level is a key enabler.
Enabler: The municipality of Deventer is also a key partner and has helped to find opportunities for upscaling the project and also to secure local renewable electricity sources.
Enabler: Successful subsidy conditions are perceived to be a critical enabler of this project. The REACT-EU subsidy first enabled the pilot phase, which kickstarted the project. Oost NL is helping to find additional subsidies for the current phase to make the business case feasible.

3. Widespread support for the project enables project

Enabler: There is support from the local government for the project, which is perceived to be necessary for getting permits and approvals. Although the local government was not present at the beginning of the project, they are now supporting the project and see it as a beneficial investment for them from a societal and economic point of view.
Enabler: There is also widespread support beyond the government, including Essent, Firan, Witteveen+Bos, and Nefit Bosch. These entities are deemed to be essential building blocks for dealing with investments, pipeline infrastructure, planning, and anchor off-take.

4. Involvement of Firan helps with momentum and transport infrastructure

Enabler: Firan provides expertise in gas infrastructure and permitting procedures, which are perceived to be very valuable to the project. Given the challenges of simultaneously reaching FIDs across various stakeholders, having close coordination with the DSO in charge of pipeline infrastructure is one of the key elements needed to get the system "*raised at once*".
Enabler: There is a perception that Firan, as a commercial entity, can have more flexibility to involve itself in such projects (plus they have their hands in other similar projects) than Enexis might be able to (given that Deventer is in an Enexis area). Therefore, strategically, they would help enable the project more than a body like Enexis would be able to.

5. Future backbone connection raises fears that locally produced hydrogen cannot compete

Barrier: There is a fear that the cost of hydrogen could outcompete that of hydrogen produced locally. Since the backbone connection timeline remains uncertain the goal is to realise the system regardless and deal with that risk in the future.
Enabler: Witteveen+Bos expects that locally produced hydrogen will be of greater value since higher purity can be maintained for use in mobility, whereas hydrogen from the backbone would require purification.

6. Insufficient electric grid connection capacity is a profound barrier

Barrier: Electric grid congestion and the inability to obtain a large enough grid connection for the original ambition for a 5 MW electrolyser is cited as the largest current barrier or "*showstopper*" at present.
Enabler: Since Nefit Bosch has a grid connection of 2.5 MW available and the permits for their hydrogen laboratory, it could help kickstart the project.

7. Communication, coordination, coalition building, and pilot phase are key enablers

Enabler: The pilot phase of the project is perceived as a major enabler, by building support and awareness for the project amongst local stakeholders. It also provided useful learnings for the project in terms of illuminating the difficulties of getting multiple companies, each with their own goals, to work together. This resulted in a strong focus on communication and coordination between parties in the ensuing commercial phase and a commitment to better messaging about the project and its positive societal impact. As a dedicated and independent communication and coordination entity, Brandeniers was brought into the project in the pilot phase and will continue with the commercial phase to help achieve these goals. Overall, having the pilot phase, demonstrating a working system (rather than simply a concept), building support, and focusing on learnings before proceeding with the commercial phase is a significant enabler.
Barrier: Coordination between parties in reaching FID is still seen as a barrier. Despite the heavy emphasis on communication, and a commitment to keeping the whole supply chain involved (by engaging with the DSO, local government, and companies), there is still the chicken and egg problem of getting each party to reach FID before the infrastructure is in place and contracts are signed.

3.5 H2 Hollandia

Box 7. Fast facts H2 Hollandia.

Location: Nieuw-Buinen, Drenthe
Starting size (electrolyser): 5 MW
Scale-up size (electrolyser): Not planned
End-use: Mobility, possible light industrial use
Other details: No planned backbone connection, driven by reducing PV curtailment

Background

The H2 Hollandia project consists of a 5 MW electrolyser located at the site of the 115 MWp PV park Vloeivelden Hollandia in Nieuw-Buinen in the province of Drenthe. The electrolyser was installed with the primary goal of reducing curtailment from the PV park and was dimensioned in such a way to optimally reduce curtailment while minimizing costs (expected to be about 50% reduction). Based on the 5 MW size that was determined, connection to the backbone was out of scope and the project was planned as standalone. The project is currently in the final stages of contracting with suppliers and off-takers and the goal is to be operational by mid-2025.

The off-taker is expected to be a single entity acting in a distributor-like role with the bulk of off-take expected in the mobility sector and the potential for some minimal use in industrial appliances. The project developers will transfer responsibility of the hydrogen at a tube trailer filling station, where they will deliver pressurized hydrogen (500 bar) to tube trailers supplied by the off-taker. Therefore, storage, transport, and dealing with variable production of hydrogen will fall entirely under the responsibility of the chosen off-taker.

The PV installation is connected to the closed distribution system (Dutch: gesloten distributiesysteem or GDS) operated by Avebe, which is then connected to the regional Enexis grid. The electrolyser is planned to be connected “behind” the PV connection point, so there is little-to-no interaction with the DSO and no new grid connection required. There are no concrete plans to scale the system beyond 5 MW, although the project maintains the possibility that a grid connection could be realised to increase the electrolyser running hours in the future and to explore grid-balancing opportunities, but this is outside the current project scope.

Drivers, enablers, and barriers

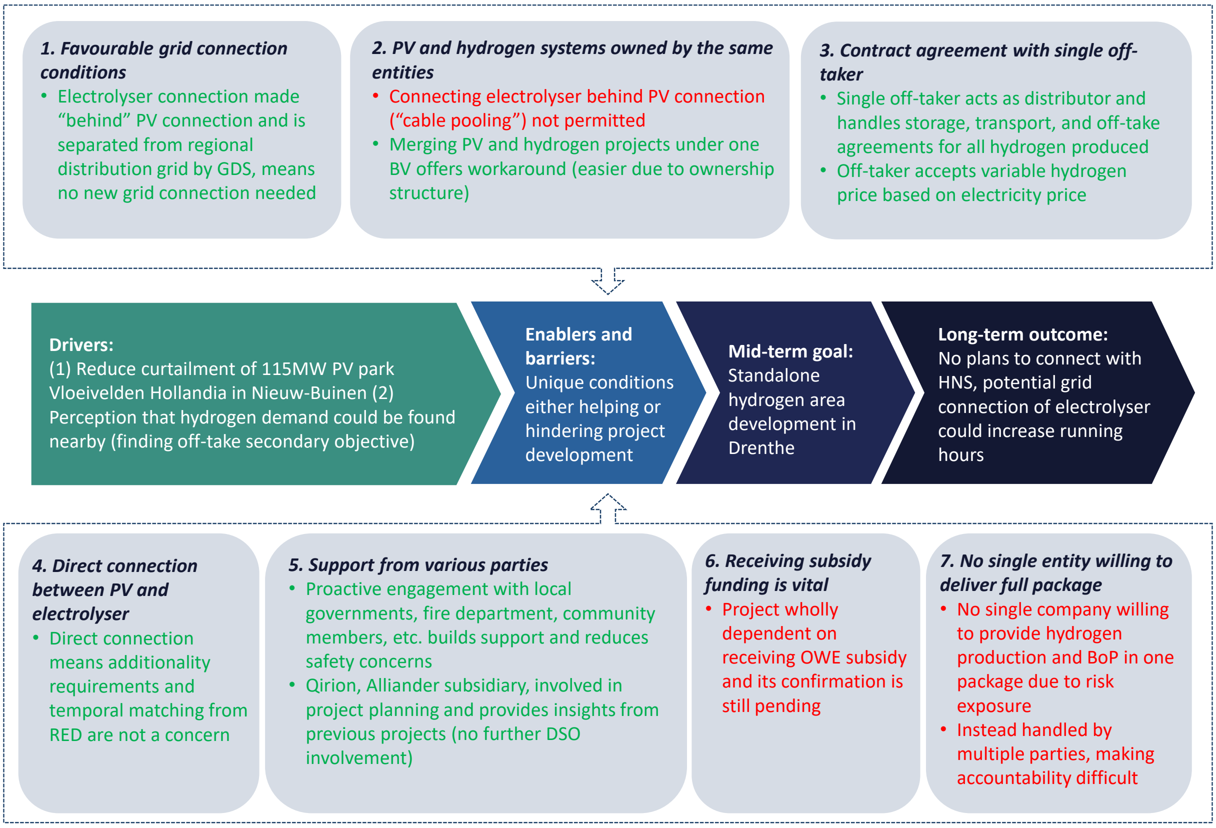

Figure 9. H2 Hollandia: Drivers, Enablers (green), Barriers (red).

The investors in the PV park and the standalone hydrogen system, Novar and Avitec, both had a desire to enter the hydrogen market, which was a key driver. Avitec’s business involves diesel-consuming heavy equipment, which initially spurred the idea that hydrogen could be an interesting solution for decarbonisation. However, given the comparatively small-scale demand expected from machinery, the project scope quickly shifted to sizing hydrogen production in such a way that would optimally reduce curtailment of the PV park, which would generate additional revenues. Distinct from many other projects where hydrogen production was motivated by the presence of off-takers, the H2 Hollandia project was designed around the concept of minimising curtailment, before starting the process of securing off-take.

The following conditions outline unique characteristics, other than the underlying drivers mentioned above, that are enabling or hindering this project:

1. Favourable grid connection conditions enable the project

Enabler: Obtaining a new grid connection is not necessary since electrolyser will be connected “behind” the PV connection. The project developers simply coordinated with Avebe, who manages the GDS, minimal interaction was needed with Enexis, the regional DSO.

2. PV and hydrogen production systems owned by the same entities enables the project

Barrier: The plan for integration behind the main PV connection, or cable pooling, is not permitted in the current legislation. This presents a legal challenge and hurdle to be overcome for the project and it is hoped that legislation will change to allow cable pooling.
Enabler: Since the hydrogen production project and the PV installation are owned by the same entities, merging the two projects under the same BV could provide a workaround to this legal barrier. Furthermore, having the same entities involved with the renewable energy supply and the hydrogen production is perceived by the project developers to be a strong enabler by having open lines of communication, and accelerating permitting and contract negotiations.

3. Contract agreement with single off-taker acting as a distributor enables the project

Enabler: Since there will be one single off-taker that will serve as a distributor, many of the typical complications (such as handling storage, transport, and off-take agreements) are out of scope of the project developers and fully in the hands of the off-taker. Given the large responsibility placed on the off-taker, the project developers emphasise the importance of finding the right off-taker, one that can organise sufficient off-take capacity, can deal with variability issues, and maintain a reliable supply chain. As an example, the project began with roughly 12 interested off-taker parties, in the end, only a third were deemed to be viable options.
Enabler: The off-takers willingness to accept a variable hydrogen price based on the cost of electricity is a critical enabler. Not only did this help reduce the risk for project investors, but it was also critical to earning the support of financing institutions: *“if you have risk in your project related to the energy prices, the bank is going to say ‘Good luck with that. We're not going to finance this because the energy markets are crazy’” (Project Manager – H2 Hollandia)*. It was perceived that industrial off-takers were much less receptive to this dynamic pricing model, whereas distributor-style off-takers in the mobility sector were generally more accepting, having become accustomed to variable fuel costs.
Enabler: Rather than investing in storage for security of supply, the off-taker is largely responsible for dealing with the variable production. Compensation agreements will be arranged to protect the off-taker in the event that hydrogen production completely ceases for unforeseen reasons (rather than importing hydrogen via tube trailer from alternate suppliers, for example).

4. Direct connection between PV and electrolyser enables the project

Enabler: Direct integration between the PV park and the electrolyser means that additionality requirements and temporal matching from the RED delegated act are not a concern for the project. Green hydrogen will be certifiably produced without concern for implications of EU regulations, which are often-cited barriers in other projects.

5. Support from various parties enables the project

Enabler: The project has strong support from the local government, as they are already familiar with the PV project, and it was not difficult to get permits. Before starting the project, the developers brought many parties to the table including the municipal and provincial governments, the fire department, and others, to discuss the project and get everyone on the same page. There was also a strong effort made to engage with the public and educate them about hydrogen to ease any safety concerns that might arise. These efforts resulted in widespread support for the project.
Enabler: Qirion, a subsidiary of Alliander, was also involved in the project planning and provided support and learnings from previous projects (this is the extent of DSO involvement, as Firan will play no role in the hydrogen infrastructure).

6. Receiving subsidy funding is of critical importance

Barrier: Despite the widespread acceptance for the project and promising off-taker negotiations, the project is wholly dependent on receiving the OWE subsidy, without it the project would not be financially viable, and its confirmation is still pending.

7. Unique barrier of not finding one entity willing to deliver full package

Barrier: The project developers were unable to find one company willing to deliver a full-package solution for hydrogen production, compression, and other balance of plant components. The project developers expressed that there was a degree of hesitancy from suppliers to accept that level of risk should something go wrong for fear of being held entirely accountable. Instead, there will likely be 3 to 4 different equipment suppliers, which could present challenges when determining what parties are legally responsible in the event of malfunctioning production.
Enabler: The project coordinated with the financial institutions behind the investments to manage this risk and determined it should be no more than 4 parties involved and there should be interface agreements in place to set in stone how responsibilities are distributed between parties.

3.6 H2avennet

Box 8. Fast facts H2avennet.

Location: Port of Amsterdam, Amsterdam, Noord-Holland **Starting size (biogasfication plant):** 55 MW **Scale-up size (electrolyser, imports, etc.):** 500 MW **End-use:** Industry, mobility **Other details:** Only standalone if producer and users move forward prior to HNS connection

Background

The H2avennet project is an open access, hydrogen distribution network planned in the Port of Amsterdam developed by Firan, subsidiary of Alliander. A relatively large grid of 15 km in the port area will be constructed that will connect multiple sources of hydrogen supply, including large-scale electrolysis, biogasification, hydrogen imports, and an eventual HNS connection, to the local demand. The scale of production is expected to eventually reach about 500 MW with the full-scale network having 17 or more connections.

The biogasification plant of 55 MW is expected to be operational before the backbone connection is available, which presents the opportunity for standalone production and consumption for a period of time. Industrial users in the area that currently demand grey hydrogen could be initial off-takers for the project by blending the green hydrogen in their processes, which provides flexibility in dealing with the highly variable supply that is expected from the biogasification plant. There are 4 to 8 potential off-takers being considered for the standalone phase, yet no contracts have been realised and Firan has yet to make an FID, as they will not start on infrastructure development without firm commitments between producer and off-takers. The project manager describes the current phase as "*detailed design*" and feels that an energy trading entity is a missing piece of the puzzle (since Firan will not take on that role). It is expected that once an energy trader steps forward, it will help bring the producer and off-takers together, determine pricing and contracts, get them to make an FID, and take the project to the next stage.

Drivers, enablers, and barriers

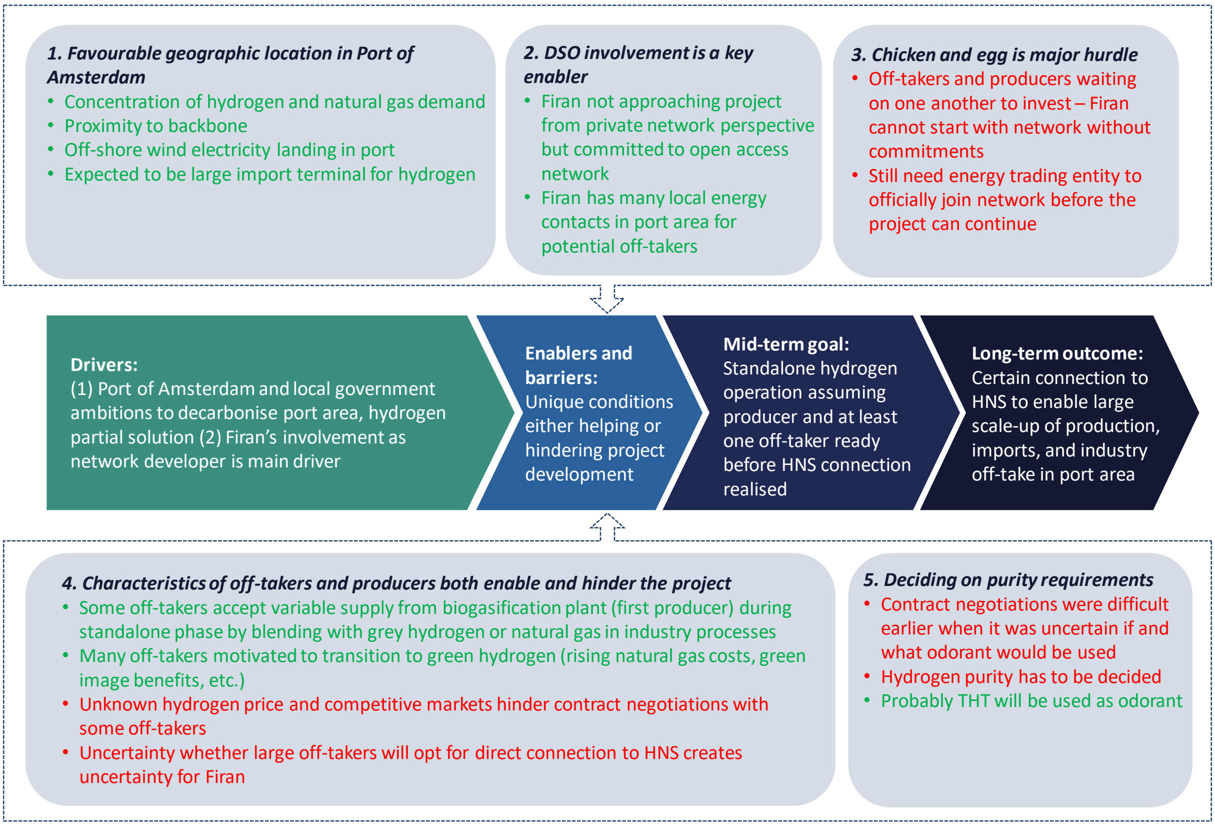

Figure 10. H2avennet: Drivers, Enablers (green), Barriers (red).

The main drivers and motivations behind this project can be traced back to the initial plans from the Port of Amsterdam and the municipality to develop strategies for local emissions reductions. The production, distribution, and consumption of green hydrogen in the port area was seen as one pathway for reducing local emissions.

However, the project is mainly driven by Firan, since they will be the ones making the investment in the infrastructure. There is a general sentiment within the parent company, Alliander, that at some point in the future they might be given the role of regulated public DSO for hydrogen networks. As such, Firan is very involved in developing hydrogen networks throughout the Netherlands and therefore there is much interest within the Alliander holding to participate in such a project. The motivation for standalone production and consumption is due to the expectation that the biogasification plant will be ready before an HNS connection is available and creating a network ahead of time can help companies begin to transition to green hydrogen immediately. It is perceived by one stakeholder (not part of Alliander or Firan) that such a project also allows Firan to get a head start on infrastructure development in anticipation of being over-burdened with similar developments in the coming years.

The following conditions outline unique characteristics, other than the underlying drivers mentioned above, that are enabling or hindering this project:

1. Favourable geographic location of the network in the Port of Amsterdam

Enabler: There are several reasons why the Port of Amsterdam is a particularly favourable location for the development of a hydrogen network. First, there is a concentration of existing and potential demand, which provides flexibility in terms of potential off-takers. Furthermore, obtaining permits for infrastructure development is expected to be easier in an industrial port area, where many companies are already working with natural gas and other chemicals. The HNS backbone will also have several connections in the port and will run from west to east. This will make it relatively easy for the H2avennet network to connect to the backbone while keeping costs comparatively lower than areas further from the backbone (although such costs are still perceived to be too high). Finally, the nearby location of expected hydrogen import terminals means there are additional sources of hydrogen supply.

2. DSO involvement is a key enabler

Enabler: It is perceived that Alliander is not approaching the H2avennet project from a private network perspective. Firan asserts that developing an open access network is more important to them than making point to point connections, which would be more profitable, in part due to the expectation that hydrogen distribution will be regulated in the future.
Enabler: Firan has contacts with local energy entities and can easily bring producers and consumers together, which is seen as a major advantage this project has over one in which an outside developer was involved.

3. Chicken and egg is major hurdle

Barrier: Despite the abundance of potential off-take in the area, there is a clear hesitance of any party to commit before supply or off-take is guaranteed respectively. Without clarity of which companies will produce and use hydrogen, Firan will not put network in the ground.
Barrier: Although there has been progress on finding an entity willing to serve in an energy trading role in the H2avennet network, this has still not been finalised, and is needed before the project can continue.

4. Characteristics of off-takers and producers both enable and hinder the project

Enabler: It is perceived that certain off-takers in the port will be able to accept the highly variable supply of green hydrogen that is expected from the biogasification unit by blending it into their current industrial processes.

Enabler: Overall, the large scale of the potential supply and demand in the port area is perceived by Firan to make it a relatively good business case (compared to other hydrogen projects).
Enabler: Increasing natural gas taxes could help convince off-takers to slowly transition their industry processes to hydrogen. Some off-takers are expected to find value in raising their product price for a greener image and therefore able to pay more for green hydrogen.
Barrier: However, given the unknown hydrogen price, off-takers in competitive markets are unable to finalise any contracts without knowing the impact it will have on their bottom line.
Barrier: Another unique barrier in this case is the lack of distinction between TSO and DSO domain in hydrogen and there is uncertainty on Firan's part whether certain off-takers will opt for a direct connection to HNS or will decide to connect to the regional grid, thus complicating their business case. Because regulation does not allow for transparency between HNS and Firan on these conversations and because there is no clear distinction between what size off-takers or suppliers should connect to which grid, this is a considerable risk that Firan is forced to take.

5. Complications relating to purity and odorants

Barrier: Unknown purity in the network and varying requirements from off-takers is a challenge.
Barrier/enabler: An odorant has to be selected. A large part of this barrier probably will be solved by deciding that an odorant will be used in the network and that this will be THT (tetrahydrothiophene).

3.7 H2GO

Box 9. Fast facts H2GO.

Location: Goeree-Overflakkee, Zuid-Holland
Starting size (electrolyser): 2 MW
Scale-up size (electrolysers): 85 MW+
End-use: Mobility, built environment
Other details: H2GO aims for backbone connection for island. Two examples of sub-projects within the program are the Greenpoint hydrogen refuelling station (HRS) and Stad Aardgasvrij and are both standalone projects developing under H2GO program umbrella.

Background

The H2GO program was initiated in 2017 by the municipality of Goeree-Overflakkee and the province of Zuid-Holland and brings a series of individual hydrogen projects and initiatives on the island under one single program management umbrella. Initially, the local governments were inspired to make Goeree-Overflakkee an energy independent island.

However, the goal of achieving energy independence was reconsidered upon realising that the potential off-take in the area was insufficient to justify such large-scale investment in hydrogen (with most potential off-take expected in the built environment and road transport, while initiatives for off-take in the maritime sector stalled due to changing EU regulations). Although coordinating the individual projects within the H2GO program to obtain an HNS connection was always within the scope of the program, it became the primary focus once energy independence was deemed unfeasible.

Nonetheless, certain initiatives within H2GO are continuing to develop independently of a backbone connection (such as the Greenpoint HRS and Stad Aardgasvrij in Stad aan 't Haringvliet). The H2GO program hopes that its support will facilitate hydrogen innovations on the island from local entrepreneurs and ultimately establish a connection with the backbone.

The current production projects planned are the following:

1. Stad Aardgasvrij in Stad aan ’t Haringvliet: a project led largely by the municipality and local residents to convert roughly 600 homes from natural gas to hydrogen. Stedin will manage the hydrogen infrastructure and Essent has been selected as the hydrogen supplier. While originally there had been plans for developing local green hydrogen production of about 18 MW capacity, it is now more likely that Essent will procure the hydrogen from another supplier on the island or import it. The project’s fate is unknown, as a March 2024 deadline for securing new subsidy funding rapidly approaches.
2. Greenpoint HRS in Oude-Tonge: a hydrogen refuelling station with 350 and 700 bar dispensers that went into operation in February 2024. Hydrogen will be imported via tube trailer in early stages but will be replaced by locally produced green hydrogen from a 2 MW electrolyser being developed nearby.
3. Van Pallandt is planning seven 5 MW wind turbines with hybrid electrolysers, for a total of about 35 MW of electrolyser capacity, but their fate is unknown due to permitting hurdles. Further, development will only proceed if a backbone connection can be realised due to insufficient local off-take for a viable business case.
4. There is also potential for a 50 MW production facility at Business Park Oostflakkee. However, conversations with potential energy supply companies are ongoing and this project remains in the early stages.

Drivers, enablers, and barriers

Figure 11. H2GO: Drivers, Enablers (green), Barriers (red).

Some initial driving forces behind the formation of the H2GO program are the following: an excess of local renewable electricity production on Goeree-Overflakkee; a general growing interest in hydrogen as an exciting new energy carrier at the time (for example, local entrepreneurs were interested in using hydrogen for a regional bus tender); and a feeling that the residents of Goeree-Overflakkee should experience some form of material benefit from the large on-shore wind capacity that had been installed on the island (amidst NIMBY concerns).

The drivers for individual projects are further explored by the enablers and barriers described below:

1. One reason for strong support from local residents in Stad aan 't Haringvliet is the price guarantee that was made, but its fate remains uncertain

Enabler: Stad Aardgasvrij in Stad aan 't Haringvliet uniquely benefits from incredibly strong and persistent support of the local residents, who remain actively engaged in the decision-making process. The initiative, spearheaded by the municipality and with the support of Stedin and Essent, actively engaged with local residents and through the series of eight promises they made (one of which being the price promise) garnered considerable public support for the program, which now continues to drive the project along. Essent and Stedin both acknowledged that this project would not have continued if not for the dedication and continued persistence of the residents.
Barrier: Interviewees from both Stedin and Essent speculated that the high degree of public support for the project is partly contingent upon fulfilling the promise made to residents that they would pay

less for hydrogen than they do for natural gas. At the time price promises were made, the natural gas price equivalents were at 90 cents per m^3, while actual prices are in the range of 120-130 cents per m^3. Hence, until now the promised 90 cents sound beneficial for the residents these days. Costs are likely not the only factor in maintaining local support, but it is expected to be much more difficult to sell such a project if residents will have to pay significantly more for the hydrogen than they would have paid otherwise for natural gas.
Barrier: The Dutch government is hesitant to subsidise a project with such low hydrogen prices for fear of undermining their push for electrification and sending a false message that hydrogen is cheap, given such prices are only possible with significant subsidies. Thus, it is unlikely that the national government will provide sufficient funding to close the delta between the hydrogen cost and the promised price and it is therefore likely that the project will come to a halt if new subsidy funding is not secured.
Barrier: The lack of clarity on the subsidy has resulted in an unclear hydrogen price, which has meant that contract negotiations with hydrogen suppliers have been unable to start, thus stalling any further progress.

2. Government regulations both enable and hinder the Stad Aardgasvrij project

Enabler: A unique enabler for this project is that Stedin Netbeheer received an exception from ACM ('gedoogkader') allowing it to oversee the regional distribution of hydrogen, without having to designate responsibility to its commercial wing, Netverder. Furthermore, Stedin received another exception allowing it to remove residents from the natural gas grid, even though there was not 100% support for the measure. This makes the Stad Aardgasvrij project very unique, as the plan is for a complete transition from natural gas to hydrogen for the city, without having a backup natural gas grid, as is the case in many other pilot projects.
Barrier: Accordingly, ensuring reliability of supply in such a network that cannot utilise natural gas for backup will be a unique challenge. It is complicated further by government regulation, originating from the gas law, requiring systems to function in temperatures as low as -17°C. Although incredibly unlikely that such temperatures would ever be seen in Goeree-Overflakkee, it further complicates the reliability of supply concerns by requiring considerable over-dimensioning of storage and delivery systems and thus increasing total system costs.

3. Involvement of Stedin and Essent in Stad aan 't Haringvliet are critical to ensuring the project's success

Enabler: Stedin's direct involvement in the Stad Aardgasvrij is perceived to be an enabler of the project (one stakeholder, not from Stedin, argued that Stedin's involvement is crucial for the project's success and it would actually be preferable to have them in a leadership role and driving the project instead of the municipality and residents). Stedin maintains some degree of scepticism regarding the role that hydrogen will play in the built environment, but at the time the project was developing it was deemed to be a strategic investment in learning to better understand what role would be possible.
Enabler: Another enabler is the involvement of Essent as energy supplier, bringing with them contacts, coordination capacity, and expertise in procuring energy contracts. Similar to Stedin, Essent finds this pilot project to be strategically advantageous for learnings and exposure in can provide by entering the hydrogen market. Essent distinctly holds the view that hydrogen will play some role in the built environment and therefore participating in such a pilot to boost their visibility in the market and accelerate learning was essential.

Barrier: However, Essent sees considerable challenges with matching the production profile of local electrolysis with the demand profile from the built environment. For this reason, and also to minimise their exposure to risk, local production of hydrogen is not a requisite. Due to the high costs of storage demanded to provide reliable supply, importing liquid hydrogen is a likely alternative.
Barrier: Although supply will be tendered, giving local and outside suppliers the opportunity to participate, it is expected that outsiders will be favoured over local producers due to their ability to provide reliability of supply. Paradoxically, while outside producers are expected to have less appetite for joining given the relative small scale of the project, they will likely be better suited to meet the reliability and price constraints of the tender, while local producers will likely have a strong desire to join but are less able to meet pricing and reliability requirements.

4. Greenpoint not reliant on backbone connection and expected to produce hydrogen locally

Enabler: The Greenpoint HRS took advantage of outside production and delivery via tube trailer in its early stages. However, local production is expected to be commissioned in 2024, serving as a unique example of local production and consumption on the island of Goeree-Overflakkee.

5. H2GO program now focused on achieving backbone connection for Goeree-Overflakkee, rather than energy independence

Enabler: It is expected that securing a connection to HNS could provide reliability of supply for local initiatives and facilitate their development. H2GO's vision is that such a connection would further drive hydrogen innovation on the island, like what is already seen by local initiatives underway.
Barrier: However, the program management for H2GO has identified a distinct challenge of getting individual parties to sign a collaboration agreement needed to demonstrate sufficient production capacity on Goeree-Overflakkee to justify to HNS that a connection is warranted. Part of this hesitancy can be attributed to "chicken and egg" difficulties of simultaneously making FIDs. It is further complicated by parties' resistance to data sharing needed for H2GO program managers to build a business case for connecting to HNS. The program manager proposed a potential solution to this by creating a secure data sharing room to be used only for the purposes of this project to encourage parties to feel more comfortable sharing data needed to further such projects without fear of losing competitive advantage or disclosing sensitive commercial information.

6. Dual perspectives on the impact of government involvement in the H2GO program

Enabler: The involvement of the municipal and provincial governments in the H2GO program is now perceived to be an enabler of the program, by funding its program management and maintaining such commitment for an extended period. The program management of H2GO now identifies the unique collaboration between public and private parties to be the biggest enabler of the program itself, by facilitating knowledge sharing and accelerated decision-making.
Barrier: Nonetheless, such sentiments of positivity toward the involvement of the municipal and provincial governments were not felt in the early stages of the program. For example, the local governments attempted to pass the costs of program management along to the other parties involved in the program, which led to tension and even the departure of some parties. It was perceived by one party formally involved in the program that changes in the provincial government and the public sector's inability to show preference to any given market party were unique challenges of a government-run program. Finally, there were also growing tensions between the local government

and other parties involved in the program early on, as some perceived the government to have been purposefully excluding local entrepreneurs from tendering processes.

3.8 Hessenpoort

Box 10. Fast facts Hessenpoort.

Location: Zwolle, Overijssel **Starting size (electrolyser):** 0.85 MW **Scale-up size (electrolyser):** 15 MW **End-use:** Mobility **Other details:** Driven by oxygen production for WDOD for use in WWTP

Background

The hydrogen production system at Hessenpoort is part of the Smart Energy Hub Regio Zwolle Noord, a project largely run by the province of Overijssel. The Smart Energy Hub plan is partly motivated by considerable electric grid congestion in the area. In fact, the nearby grid station was the first in the province where renewable electricity could no longer be fed into the grid. Further, due to abundant space for renewable development, the area is uniquely positioned to expand its renewable production but limited by available grid capacity. Therefore, the province wanted to explore opportunities with Enexis and Tennet to better manage energy production and consumption.

One such idea for intelligent energy management was the development of a hydrogen production system. Such a system had been studied by the municipal water board (Waterschap Drents Overijsselse Delta or WDOD) to reduce their electricity demand in the wastewater treatment plant (WWTP) by utilising waste oxygen produced during green hydrogen production, rather than the energy intensive process of using atmospheric oxygen. The WDOD's demand for oxygen was complimented by a local entrepreneur's interest in hydrogen to fuel heavy transport machinery used in producing and transporting road building materials.

The province connected these two parties who decided to share in the investment of the hydrogen system. With help from the REACT-EU subsidy, the project has taken shape and installation of the system, including a 0.85 MW electrolyser, is expected to be completed mid-2024. The director of the Smart Energy Hub anticipates that hydrogen production could be scaled up to a maximum of about 15 MW to serve the oxygen demand from another WWTP in Zwolle. But if local industry or mobility off-takers demand exceeds this capacity, based on the maximum oxygen demand, the hydrogen would likely be better supplied by the backbone, according to the director.

Drivers, enablers, and barriers

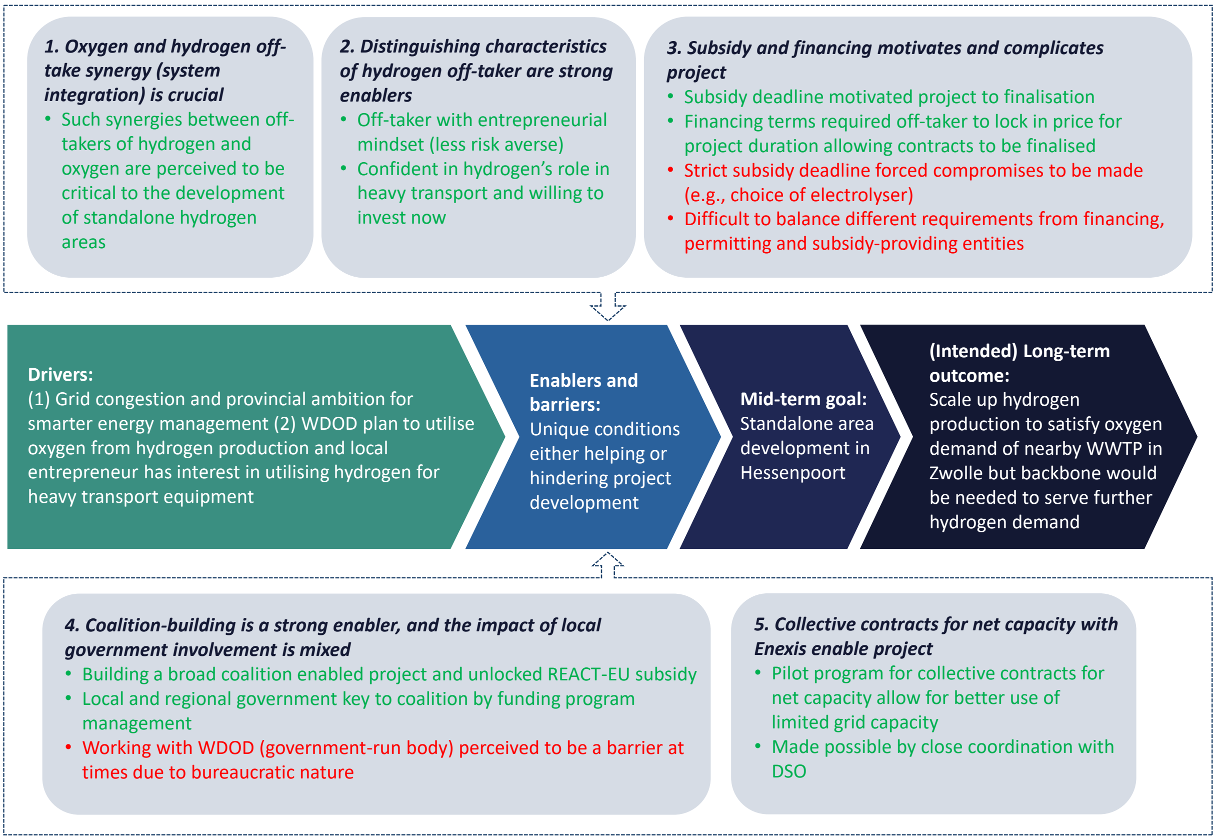

Figure 12. Hessenpoort: Drivers, Enablers (green), Barriers (red).

The underlying drivers for the Hessenpoort project are two-fold: the electric grid conditions in the local area and the local interest in hydrogen and oxygen off-take.

The underlying drivers for developing a hydrogen production system can be credited to the interest in hydrogen from the local entrepreneur and the model of the WDOD to utilise oxygen from local hydrogen production in its water treatment process. Taken together, the underlying desire to develop innovative energy balancing solutions considering abundant green electricity potential and low grid connection capacity, coupled with an apparent demand for both hydrogen and oxygen, led to the development of this project.

The following conditions outline unique characteristics, other than the underlying drivers mentioned above, that are enabling or hindering this project:

1. Oxygen and hydrogen off-take synergy (system integration) is very favourable for development of local standalone hydrogen production

Enabler: The synergy between off-takers for hydrogen and oxygen is key to the successful development of the project. The WDOD's interest and extensive planning and testing of utilising oxygen from hydrogen production in its processes combined with the interest from a local entrepreneur in off-taking any and all hydrogen produced by the system are clear motivators that have helped the project keep its momentum. Finding such opportunities for synergies and system integration is perceived to be crucial to enabling such standalone projects.

2. Distinguishing characteristics of hydrogen off-taker are strong enablers

Enabler: Having a hydrogen off-taker with an entrepreneurial mindset and who is less risk averse than other off-takers is a key enabler. Further, the off-taker is confident in hydrogen's role in heavy transport and that sufficient off-take can be found. Further, the director of the project holds a similar view that the role of hydrogen in mobility is inevitable, especially from the perspective of grid congestion: *"we all will find out [in] the next five years that Enexis and Tennet and the other grid managers are not able to provide [capacity]. It's not possible to strengthen the electricity net to the amount that is asked for now. So you have … no use for [an] electric truck if you can't [charge] it. So I think the market will reinvent that it was a good idea to not only focus on electrons, but also on molecules, and that hydrogen will get a bigger role also in transport."*

3. Subsidy and financing simultaneously motivates and complicates project

Enabler: Although referred to as one of the largest hurdles that had to be overcome, the deadline imposed by the REACT-EU subsidy was a clear motivator and enabler of finalising the project in a short time frame (not to mention the fundamental importance of the subsidy in enabling the business case).
Enabler: Often uncertain hydrogen prices can hold up off-taker contract negotiations. In this project, the financing body forced the off-taker to lock into a single price for the duration of the project. Although largely to the off-taker's dismay, who would have preferred some flexibility in the hydrogen price, the terms of the financing company, Energiefonds Overijssel, required a contract for the total volume of hydrogen produced, which led to everyone being able to make an FID. According to the director, the off-taker now at least has *"the insurance that he has a moderate, but good enough business case."*
Barrier: The subsidy required decisions be made in an accelerated manner that were sub-optimal but necessary to keep the subsidy. For example, the original plan was to purchase a Dutch electrolyser that would deliver the oxygen at the appropriate pressure for the WWTP. However, since it could not be delivered before the end of 2023, which was a requirement of the subsidy, the project was forced to procure a German electrolyser. As a result, an additional unit was needed to pressurise the oxygen to the appropriate level, since the output pressure was lower than that of the original unit.
Barrier: Balancing the requirements of the various funding sources (e.g., those of the subsidy provider and the regional financing company) proved difficult. For example, *"the permits … could only be a temporary permit for five years. For the financing, it should be a business case for at least 15 years. So all those different requirements did not fit and we had to sail between the cliffs, so to speak. And that makes such [an] innovation project very complicated" (Director – Hessenpoort)*.

4. Coalition-building is a strong enabler and the impact of local government involvement is mixed

Enabler: Building a coalition is perceived to be one of the largest enablers of the project. Such broad cooperation is necessary in systems without clear ownership, such as the regional energy system, which in the past was top down and now involves multiple production sites and lacks a clear steering body, since traditional DSOs are unable to invest in batteries or electrolysers, for example.
Enabler: Without such a coalition, it is expected that the REACT-EU subsidy would not have been possible.
Enabler: The local and regional governments play a key role here by supporting the development of such a coalition. The province of Overijssel funds the project management, which is responsible for keeping all involved parties together, coordinated, and on track. Together with the municipality of

Zwolle, there is quite some public funding invested, which is perceived to be absolutely necessary for getting such projects off the ground, where the market is not quite ready.
Barrier: The involvement of the WDOD, although a crucial partner, was also perceived as a barrier at times due to the bureaucratic nature of its decision-making process. For example, the decision to proceed with a German electrolyser instead of the original choice proved challenging because additional compressor required a new subsidy be obtained by the WDOD. According to the project director, when dealing with a government-run body like the WDOD, *"you should not change the project after the decisions are made. That's also very difficult,"* in reference to the delays caused by the additional subsidy application process.

5. Collective contracts for net capacity with Enexis enable the project

Enabler: The coalition is working in close coordination with Enexis to pilot collective contracts for net capacity. This allows for local energy management and balancing "behind the meter" and for a more intelligent use of what limited grid capacity is available. The plan is to integrate the electrolyser into one of these collective agreements, thereby providing the *"ability to use the grid capacity collectively much smarter than you do now individually. So the idea is that some companies that are not allowed to put their overproduction of solar energy on the grid … are allowed then as long as the electrolyzer is running … it absorbs all [that] production and also the [charging] facilities of the bus company and so on. … We get the right to steer on the collective use of the net capacity as long as we stay within the range that we made a contract over with Enexis" (Director – Hessenpoort).*

3.9 Zephyros

Box 11. Fast fact Zephyros.

Location: Den Helder, Noord-Holland **Starting size (electrolyser):** 2 MW **Scale-up size (electrolyser):** 200 MW **End-use:** Mobility (marine and road) **Other details:** Scale-up driven by potential to supply backbone

Background

The Zephyros project will produce green hydrogen for the mobility sector in the area around the Port of Den Helder (PoDH). The 1.5 to 2 MW electrolyser planned for the initial pilot phase will be located in the inner port, along with a fuelling station from Total Energies for maritime and road transport. A key aspect of the project is a focus on building demand for hydrogen in the maritime sector through demonstration projects and outreach to potential local off-takers. For instance, the small hydrogen-powered vessel from H2 Marine Solutions is a functional vessel that has been used in trials by potential off-takers to familiarise them with the technology and build interest in the local area.

The Zephyros project also plans to serve hydrogen demand from larger companies using hydrogen in their vessels. One potential off-taker is in the process of converting an existing vessel and another is currently operating hydrogen ferries out of Ijmuiden. It has been deemed a viable business case to transport the hydrogen via tube trailer to supply this demand.

Recently, also the goal for congestion management has become more prominent on the agenda of the project. The electrolyser investor, Liander, and InHolland are coordinating constructively how the project can help to relieve the area from congestion related issues.

In a later scale-up phase, a pipeline could be required to connect the production location located at the inner port to the open seaport area, to provide a bunkering facility for methanol or hydrogen to serve eventual demand from the Royal Netherlands Navy and the offshore maintenance vessels for oil and gas projects as well as offshore wind development. The energy company investing in the electrolyser is expected to scale the production capacity tremendously to receive an HNS connection and supply the backbone.

Drivers, enablers, and barriers

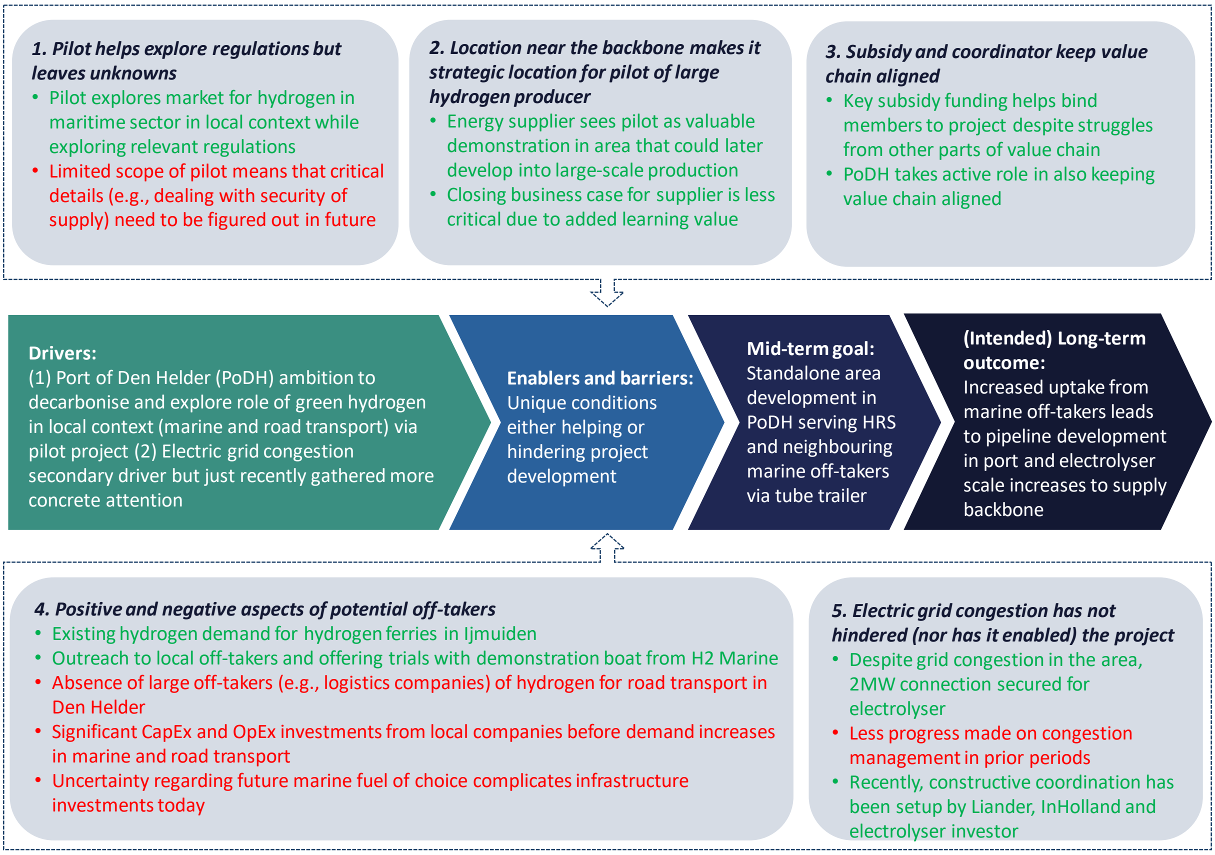

Figure 13. Zephyros: Drivers, Enablers (green), Barriers (red).

The Zephyros project is largely driven by the PoDH's commitment to developing the complete hydrogen value chain in the port area with a focus on off-take in the maritime and road transport sectors. An underlying driver of the project was to investigate the role that such a project could play in electric grid congestion mitigation, yet this has not played a role so far.

The following conditions outline unique characteristics, other than the underlying drivers mentioned above, that are enabling or hindering this project:

1. Pilot project helps explore regulations but leaves many unknowns

Enabler: The pilot nature of the project is meant for exploring the market for hydrogen fuels in the maritime sector and proving the value chain. There are many learnings to be taken from such a project and built upon in the future, for example, *"there's not a whole lot of safety regulation on the field of hydrogen already in place, not in the production, not on the transportation and also not in the use part of the hydrogen chain. So this is one of the reasons for doing a pilot like this as well to explore what kinds of regulations you need and to work your way through it and to get the environmental services on your side to be guaranteed a developing space for making use of it" (Deputy Director PoDH – Zephyros).*
Barrier: There are not yet plans for guaranteeing reliability of supply, as it is outside of the project scope now due to its pilot nature. It therefore remains to be seen the degree to which similar projects really can be viable.

2. Location near the backbone makes it strategic location for pilot of large hydrogen producer

Enabler: The large energy supplier that will be responsible for the 2 MW hydrogen production finds value in this demonstration project being used to serve the local maritime and road transport sectors in the PoDH area. It comes with the added benefit that they are less concerned with closing a business case at this scale, as it is meant as part of a larger research program into eventually supplying hydrogen to the backbone at a larger scale. Thus, finding sufficient off-take at a low enough price is less of a priority than it otherwise might be.

3. Subsidy and designated coordinator keeps parties in value chain aligned

Enabler: Key subsidy funding, for example that which is funding the HRS, is perceived as a critical mechanism for keeping the value chain from falling apart. From the PoDH perspective, major stumbling blocks, such as losing the original hydrogen supplier, might have caused other members of the value chain to falter or pull-out, but instead the subsidy, *"binds them really to finalising the project,"* and provides the "*leverage*" needed to keep those members of the value chain from leaving.
Enabler: Along with subsidies, the project believes that it is the responsibility of the port and the business developer to be active and committed to keeping the value chain in line.

4. Positive and negative aspects of potential off-takers

Enabler: The presence of an off-taker with existing hydrogen demand in the maritime sector is a unique enabler of the project. Since one company is already using hydrogen boats operating out of Ijmuiden, it provides a unique opportunity of off-take in a market that is still far from maturity by delivering weekly supplies of hydrogen from Den Helder to Ijmuiden.
Enabler: The project is committed to building support and increasing awareness among potential maritime off-takers through H2 Marine's demonstration boat and have invited potential users to perform trials with the boat to get acquainted with the technology and boost interest.
Barrier: For road transport, Den Helder faces the problem of not having large logistics companies and instead must target small transport buses which have not yet entered the hydrogen market. Furthermore, there are significant barriers to be overcome when it comes to the CapEx and OpEx of marine vessels operating on hydrogen. *"The vessels and … trucks are both not available or very expensive. So they need some help in doing these investments and most of the subsidies are supporting in the CapEx only and not so much in the OpEx" (Deputy Director PoDH – Zephyros).*

Barrier: There remains much uncertainty regarding the future sustainable fuel of choice in the maritime sector. While it is a goal of this project to get clarity on which fuel will take hold, pilot stages need to be accomplished to better understand demand before large-scale infrastructure investments can take place (for example, the potential methanol or hydrogen pipeline between the inner and outer port areas in Den Helder).

5. Electric grid congestion has not hindered (nor has it enabled) the project

Enabler: Despite heavy grid congestion in the area, a 2 MW grid connection for the electrolyser in the first stage of the project has been secured, assuming a connection can be made within two years' time. From the PoDH perspective, they are quite pleased with this, and it is perceived to be very important for the "*tempo*" in developing such a project.
Enabler/Barrier: Despite the project's original goal to play a role in congestion mitigation, less progress has been made on this topic over the prior period. Relatively recently, a constructive coordination has been set up by the electrolyser investor, Liander, and InHolland Liander to explore and prioritise the matter.

4. Cross-case results and learnings from Standalone Hydrogen Cases

This chapter presents the results of an analysis comparing the perceptions of interviewees from the different cases on specific topics. An overview of the topics and the key contents from the cross-case analysis is shown in Table 3. In the next subchapters the topics and insights are discussed in greater detail. Besides understanding the differences between the nine investigated standalone hydrogen areas, the insights in the next subchapters can be used when designing or developing potential new standalone hydrogen areas in the future.

Table 3. Overview of cross-case analysis of standalone hydrogen areas (SHAs) and key insights described in chapter 4.

Topic	Key insight / content
Roles & responsibilities in SHAs	7 roles are identified that occurred in all investigated standalone hydrogen cases. Also, considerations for involving the local government and selecting the DSO party are summarised.
Regulation & legislation	No different legislative issues were mentioned for standalone hydrogen areas, compared to hydrogen projects in general.
Role of SHA in hydrogen infrastructure development	Some standalone hydrogen cases intend to prepare the region well for a future backbone connection, while others are standalone on purpose and potentially can be replicated in other areas.
Technical characteristics of standalone hydrogen cases	Mostly, a limit to the size of standalone hydrogen projects is observed. Thus, higher pressure and purity standards are desired when local electrolysis and fuel cell applications are in the system.
Electricity grid congestion	Congestion can be a major barrier when a grid connection is needed for the electrolyser. But multiple practices were seen to reduce or remove to congestion limitations.

4.1 Roles and responsibilities

Seven key roles were observed in all researched standalone hydrogen cases (see Figure 14), and filling such roles is likely key for potential standalone hydrogen areas to be developed in the future. Multiple interview participants described that in order to get a standalone project off the ground, there should be one party or person that keeps an overview of the whole project and all stakeholders involved. For example, the project coordinator of Hessenpoort stated: *''I think the broad cooperation we built is an enabler. So this is typical in a subject that has no owner. So we try to balance everybody in this regional system. It is something that was not needed in the old system.''* Also, in the GROWH project there is a clear project coordinator: *''Well, obviously Witteveen+Bos is the connector, but there are more participants necessary.''*

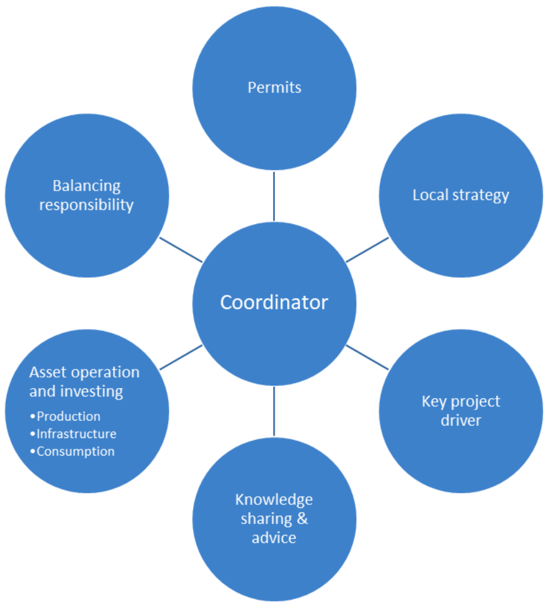

Figure 14. Overview of 7 key roles in standalone hydrogen areas.

Also, in every standalone case a key project driver was seen. Such party has considerable interest in the initiative and serves as a driving force for the project to develop. However, in many cases without the commitment of the key driver, such standalone cases will not be realised. The involvement of the datacentre in the Agriport A7 project is illustrative of this: *''And in the end, to make a decision, it's up to them [datacentre] whether they want to invest in it because it's a lot of money. It has to come from the datacentres which must be willing to invest to reduce or eliminate the emissions (of the backup power). They want 24/7 green energy even when there is no wind and no sun.''* The coordinator and key project driver roles can be held by two individual parties or by one sole party.

Thirdly, there is the knowledge and advising roles. Next to advising companies and freelancers, the private subsidiaries of the grid operator, like Firan, Qirion and Netverder, were also named multiple times as important knowledge providers for the projects: *"we did talk to Qirion who was also involved in the Sinnewetterstof project … they helped us with structuring the basic engineering for the permits and how to involve the right parties for permitting'' (H2 Hollandia).*

Another specific role that was named was the balancing responsibility. The bigger standalone projects (e.g., GROWH, H2avennet, and H2GO) foresaw an energy supplier taking this role, while in some of the smaller standalone projects the off-taker was made responsible for this: *"And so for us it was a clear decision to scope the project up to the tube filling station and then leave the whole distribution and balancing to the off taker, when this party is willing to accept the seasonal difference in production properly.''* (H2 Hollandia).

The final three roles are more straightforward. Permitting is an essential part of these projects and the regional governments are responsible for this. Also, municipalities were directly, or indirectly seen to be responsible for accepting the pilot as part of the overall regional strategy. Finally, there are the parties that invest in the assets (production, transport, and consumption) and operate them.

4.1.1 Involvement of the local government

How local government involvement is organised in a standalone area is a critical consideration in its development. This is because the local government is a special stakeholder in the standalone areas. First, they must be involved to develop a standalone area, due to the permits that are required. Second, in this phase of hydrogen developments the interest of local governments is a strong driver, and without it, the economic, legislative, and societal barriers would be even more difficult to overcome.

The different types of government involvement in the researched standalone cases are summarized in Table 4.

Table 4. Overview of government involvement in the researched standalone hydrogen cases

Type of government involvement	Standalone case
Initiator and main driver	Bolsward, H2GO, Hessenpoort
Strong government involvement via harbour	H2avennet, Zephyros
Collaboration with government on permits	GROWH, H2 Hollandia, Duwaal
No government involvement (yet)	Agriport A7

In the Bolsward, H2GO and Hessenpoort projects the local government was the main initiator to set up a regional standalone hydrogen system. In the Bolsward project the municipality really wants to integrate multiple local energy initiatives to create a beneficial energy ecosystem for the region. The start of H2GO was initiated by the local governments who financed a project coordinator to align all the different initiatives that were going on at Goeree-Overvlakkee. The Hessenpoort project was initiated in close coordination with the province Overijssel and the wastewater treatment plant, which are operated and owned in the Netherlands by the governmental water authorities (Dutch: ‘Waterschappen’). A main consideration of projects that are really driven and owned by the municipality is that the activities should be tendered in an open and transparent way. One example is the construction and ownership of the pipeline system foreseen in the Bolsward project: even if there would be contact with a suitable party to perform this task, it should be tendered and assigned in an open and transparent way. Another example is the supply of hydrogen to Stad aan ‘t Haringvliet as part of the H2GO project. There are some local options to supply this hydrogen, but if a better bid is made by a producer elsewhere, this party will be selected. Hence, the municipality as initiator comes with some obligations.

Another type of government involvement was seen in the H2avennet and Zephyros project. The harbour organisations had a big role in initiating these two projects and the municipalities are the shareholders of these organisations. Moreover, the harbours determine how the land in the harbour area is used and thereby have a role in setting out the regional strategy in these areas. Another enabler of government involvement is that they can be one of the launching customers of the local initiatives. One stakeholder involved in the Zephyros project expressed the sentiment that Den Helder has a strong role to play in stimulating the demand for the filling station and demonstrating that they as port are committed to becoming an offshore industry and hydrogen hub by purchasing a hydrogen-fuelled boat themselves, but this remains to be seen.

Finally, in order to realise a standalone hydrogen project, there should be collaboration with the municipality in order to obtain the required permits. This was the case for GROWH, H2 Hollandia, and Duwaal, which all initially started from interests of private parties. Agriport A7 currently has no government involvement but foresees that collaboration with the municipality will be required as well when the project moves to the permitting stage. The project manager of H2 Hollandia articulates what they found to be the best practice for involving government early on while successfully developing a privately initiated standalone hydrogen area: “*The municipality is really important as I already mentioned. I mean it’s all new for them and that can basically go two ways. So either they just jump on the brakes when you come there, because it is all new and unknown. And the other option is: OK, this is really interesting, let’s make this happen and look to the opportunities … We talked a lot about different governmental organizations in order to make sure that everybody was aligned before starting the permitting phase. We had a really large starting meeting with all these different governmental bodies, also with the fire department about the safety route. We had an open discussion and then we concluded with: OK, I think everybody agrees that this is an amazing opportunity for the region. Let’s make this happen.*’’

Table 5. Summary of main considerations of the type of local government involvement.

Considerations for strengthening government involvement	Considerations to limit government involvement
Alignment with regional strategy and public interests	Government as initiator means that legal processes such as open and transparent tendering have to be followed
Collaboration on permits is a must	
Government as initial off-taker	

4.1.2 Involvement of a DSO and/or its subsidiaries

Between the investigated standalone hydrogen cases different considerations on how and what parties to involve as DSOs were seen, based on the objectives and needs of the projects. However, in every project an electricity and/or potential hydrogen grid operator was involved. Therefore, this is a consideration that matters for every standalone hydrogen area and the decision is not always obvious: *"If the interest becomes bigger, then you need to have somebody … that says … I'm going to be the owner now of this infrastructure… you would expect for these decentralized things that you could use the current sitting DSOs … But that's not happening. Not yet" (Equipment supplier – Duwaal).*

Table 6. Overview of DSO involvement in the researched standalone hydrogen cases.

Type of DSO involvement	Standalone case
DSO involvement to get electricity grid connection	Bolsward, Zephyros
Limit size needs of electricity grid connection	H2 Hollandia, Hessenpoort
Involvement DSO for hydrogen distribution grid	H2avennet, GROWH, H2GO
Cases with privately owned hydrogen pipelines	Duwaal, Agriport A7

Table 6 summarises the DSO involvement for every case. The minimum DSO involvement was seen in Bolsward and Zephyros. Both projects only have the DSO involved to get the electricity grid connection. Both projects were willing to have a closer collaboration with a grid operator. The municipality of Bolsward investigated if Firan wanted to invest and operate their pipeline system, but at this moment Firan has multiple pilot projects going on (i.e. H2avennet and GROWH) and has insufficient capacity at this moment to support every project, while it is still not certain if any entity of their mother company, Alliander, will be publicly assigned as hydrogen distribution operator. Zephyros also wants to explore whether their electrolyser could be used to relieve stress on the electricity grid but has not yet been able to coordinate with a grid operator on this. Hessenpoort has such contact with the grid operators and is involved in a national program of Netbeheer Nederland to explore new types of contracts to optimize the electricity grid capacity usage in a Smart Energy Hub.[4] The 5 MW electrolyser of H2 Hollandia will also be built to utilize more solar energy with a smaller electricity grid connection. The electrolyser and the 115 MWp solar PV field are connected to the closed distribution system (GDS) of Avebe, such that 'only' a 60 MVA electricity grid connection is contracted.

H2avennet and GROWH have Firan as a DSO subsidiary interested in investing and operating the planned hydrogen distribution grids in these areas. The three main reasons why Firan was chosen is that they have the experience and knowledge of gas distribution, that they are known with the parties and potential customers in the region, and that they can spread the investment risk over a long period. Stad aan 't Haringvliet in the H2GO program uniquely involves Stedin Netbeheer (as they received an exception from ACM to participate in the project with their regulated body without having to defer to their commercial subsidiary, Netverder) in the project for similar reasons relating to their knowledge and expertise and is perceived by another stakeholder in the project to be a crucial party to have in such projects. For the Agriport A7 project, the private DSO, ECW, is involved and operates a private electricity, heat, CO_2, water, and gas grid in this area and is owned by the local greenhouses. Similar to Firan, they bring to the table a deep knowledge of the local energy system and contacts with relevant parties there.

[4] See RVO's "Samenwerken in energiehubs" for more information [17].

Not all projects opted for involving a DSO (private, public or one their subsidiaries). In the Bolsward project, there was strong desire to choose a hydrogen DSO with public interests who will guarantee an open access network if additional customers are interested in connecting. Therefore, the municipality is considering taking ownership of this network to fill the role of the DSO (and contract an outside company with technical expertise to operate the system). In the Duwaal project, on the other hand, there were other reasons that prevented them from collaborating with the parties that are currently assigned as public grid operators for natural gas: "*Especially because already quite early on, I had a meeting with Liander and Gasunie and that's where for the first time I realized that Gasunie is not interested in the regional pipelines and Liander has problems with pipelines that have a higher pressure than 8 bar. So for those reasons, it was clear that we're going to operate independently from any operator.*" The more traditional view of natural gas transport did not fit with the opportunities that were seen by the project developers of the Duwaal project: pure hydrogen produced by a local electrolyser at 30 bar that could be transported by a pipeline to mobility applications that request high purity and quality as well. Moreover, by operating the pipeline at a higher pressure the pipeline could also be utilized as means of hydrogen storage. Nonetheless, HYGRO acknowledges that should a DSO party decide to operate at pressures above 16 bar their involvement in the project would be welcomed.

Table 7. Summary of main considerations to determine which party should serve as DSO in the standalone area.

Factors that could benefit a certain DSO party	Factors that could withhold a certain DSO party
Experience & knowledge	Regulative constraints
Guarantee for open access network & public interests	Willingness to operate at low pressure only (e.g. <16 bars)
Network & contacts of parties in the area	Lack of capacity to be involved in the project
Spread investment risks over long period	

4.2 Regulatory requirements

Many of the interviewees have mentioned regulatory and legislative barriers that are or were faced by their standalone project. However, while analysing these regulatory issues, **it became clear that many of these regulatory issues are similar to those seen in hydrogen projects in general**. Therefore, the interviews did not lead to insights in regulatory or legislative issues that are specific for standalone hydrogen projects or areas. What became clear is that for some of the projects, the speed of development (and therefore sometimes also partially the decision to start standalone) was driven by the exception of the RED delegated act on additionality that is less strict if an electrolyser is commissioned before 2028.[5]

Some of the general issues with regulation were the following:

- It is unclear if specific regulation on hydrogen will be implemented and uncertain what decisions will be made when it is implemented.
- Existing legislation is unclear in many cases and/or might change in the short term.
- Existing legislation is complex to find and understand; and sometimes also unaligned.
- Permitting often takes a lot of time and permitting periods are typically shorter than the duration of the business case.

[5] Further information on the *Delegated Act on a methodology for renewable fuels on non-biological origin,* which sets guidelines for defining renewable hydrogen can be found here [15].

- Differences in perception whether regulation should stay the same or differ from existing natural gas laws.

Some specific examples of regulatory and legislative issues that were mentioned are shown in Table 8.

Table 8. Overview of regulatory and legislative enablers and barriers named by the interviewees. (note that this is a list of all the regulatory barriers named, so each is named at least by one person and not all interviewees have to agree with them)

Production	**Transport & storage**	**Consumption**	**Trading**
RED III • No in-turbine H2 • Strict after 2028 • Favours direct connection	Regulation H2 distribution and whether private pipelines will be taken over if public DSO would be assigned	More focus on end-user support & equal support for different applications	Difficult for local trading initiatives to become licensed energy traders
Cable pooling	Grid pressure & permits	Uncertainty taxes on hydrogen	Collaborative contracts for net sharing
EU hydrogen bank	Odorization	HBE price uncertainty	
	Safety regulations	NMDA regulation[6]	
	Exceptions pilots	Removing households from natural gas grid	
	Unclarity about roles of TSO and DSO, and no system connection agreement yet.	Dutch gas law states that gas supply should be large enough that houses will stay warm even at -17°C outside temperature.	
	Connecting import & storage terminals to DSO		
	Cross-finance natural gas and hydrogen grids		
	Perception that non-metallic pipes should become standard		

4.3 Role of standalone areas in hydrogen infrastructure development

The degree of hydrogen infrastructure roll-out observed across cases depends largely on the intended end-use and the plans for scale-up and backbone connection in the future. Some cases specifically intend to develop local hydrogen infrastructure to prepare the region well for a future backbone connection, others plan hydrogen infrastructure to connect producers and off-takers

[6] 'Niet-Meer-Dan-Anders beginsel', literally translated: 'No-More-Than-Otherwise principle'. It is one of the starting points of the 'Warmtewet' (heating law) that users in the built environment do not pay more on their energy bill than they would otherwise have paid if they would still use a natural gas boiler.

despite an uncertain backbone connection, while others do not intend to roll-out any pipeline infrastructure as it is not required by their use case.

*Table 9. Overview of case study areas hydrogen infrastructure roll-out plans and their intention to connect with the backbone. *Agriport A7 is unsure of a backbone connection but it will be needed for greenhouses. **Bolsward and GROHW would both need a backbone for 100% transition from industry off-takers but are planning currently for standalone operation.*

	Strong push for backbone connection	Potential backbone connection but unsure	No planned backbone connection
Pipeline infrastructure in early stages	Agriport A7*, H2avennet	Bolsward, GROHW**, Stad Aardgasvrij (H2GO), Duwaal	
Pipeline infrastructure in later stage		Hessenpoort, Zephyros	
Regional distribution grid not planned		Greenpoint HRS (H2GO)	H2 Hollandia

For many of the standalone areas, a regional gas grid is already planned for the initial stages of the project. In such cases, a grid is needed to connect hydrogen supply to one or more off-takers. For areas anticipating (or striving for) a backbone connection, a regional grid is needed to not only connect producers and off-takers in the standalone phase, but also to eventually distribute hydrogen from HNS to off-takers when a connection has been realised (Agriport A7, H2avennet). It was perceived by one stakeholder in the H2avennet project that investing in a regional hydrogen grid before the backbone is realised could prevent bottlenecks in infrastructure roll-out when the hydrogen market matures, and demand increases rapidly.

Although many areas hope to get a connection to improve security of supply, the timing and likelihood remains uncertain. Geographic characteristics of off-takers can cause them to proceed with regional grid investments despite uncertainties. For example, geographic concentration of industrial off-taker demand (Bolsward, GROHW), or more efficiently transporting hydrogen in a high-pressure pipeline from the electrolyser to a distribution hub (Duwaal – see also 4.4.1) could motivate such investments.

Finally, the end-use of hydrogen could inform the degree of infrastructure roll-out. The regional grid planned for the Stad Aardgasvrij project (within the H2GO program) will utilise the local natural gas distribution grid for heating of homes. A new pipeline from the production site to a storage/feed-in station is foreseen if hydrogen is produced locally, whereas if it is imported into the region, only a storage/feed-in station will be realised. Other projects serving the mobility sector often do not foresee regional grid roll-out and instead plan to use tube trailers (H2 Hollandia) and possibly a regional hydrogen pipeline in the future if demand scales up (Zephyros, Hessenpoort).

Security of supply is a concern in these regional grids and is typically a motivator for a backbone connection. On the other hand, the backbone can also provide storage for regional hydrogen surpluses. There is often some kind of storage facility planned in the standalone areas, either at a central storage location or at the off-taker. However, typically tube trailers are planned for storage, which is a suitable option for the initial small scale of these projects but will be partially redundant after a potential future connection to the hydrogen backbone (although local high-pressure storage could still be necessary for HRS). Security of supply can also be improved by smart design of the pipelines. For example, in Bolsward a dual pipeline system (hydrogen and natural gas), in conjunction with limited central storage, are considered to improve the balance of the system. Finally, before the backbone is realised, decentral areas can also be connected to each other to improve security of supply. For example, the

Agriport A7 project has considered a possible pipeline to connect to the electrolyser of HYGRO (Duwaal) but ownership of such a pipeline remains uncertain.

It should be noted much uncertainty remains regarding how ownership of private infrastructure will evolve in the future. For instance, Soluforce (composite pipe manufacturer) stated that they often get the question whether HNS plans to take over private hydrogen pipelines in the future and the project coordinator for Duwaal expressed a similar degree of uncertainty on the matter. For the development of hydrogen infrastructure by private parties, it is important that the regional networks are held to the same standards as that of HNS (Gasunie) if infrastructure is to be taken under their ownership. However, at this moment it is unclear what these standards are and how best to proceed.

4.4 Technical characteristics of hydrogen infrastructure

In this chapter considerations on the hydrogen pressure, quality, and volumes in the standalone areas are discussed. Higher pressure and quality standards are often desired when local electrolysis and fuel cell applications are present in the system, compared to what is being expected from the backbone (in terms of quality) and what is typically standard for DSOs of natural gas (in terms of pressure operating limits). The rationale for anticipated volumes of production and potential scale-up limitations varies by project and are explained further.

4.4.1 Pressure

For natural gas, the DSOs operate gas grids of 0.1-8 bar and in some cases 16 bar, while the TSO operates gas grids above 16 bar. Currently, it is expected by most of the interviewees that the hydrogen grid will be operated in a similar way. However, whilst for natural gas there are relatively few large feed-in points in the high-pressure backbone, for the hydrogen grid it is a possibility that there will be a much larger number of feed-in points with the smaller projects often feeding into the regional gas grid. The challenge for feeding into the regional gas network is that hydrogen produced by an electrolyser is produced at 30 bar. If DSOs assume similar operating pressure limits to natural gas, the maximum pressure they will be allowed to handle will be 16 bar, which means that the hydrogen pressure should be reduced in order to be fed into the regional network. However, in the case of an end-user that requires high pressure (specifically mobility, but also some industries) this is a waste of energy and money as the hydrogen should be pressurized again at the end-user. Despite more clarity regarding a delineation between roles of hydrogen transmission network operators (TSOs) and distribution network operators (DSOs) in the EU directive to establish common rules for the internal markets in renewable and natural gases and in hydrogen, some interviewees expressed lingering uncertainties regarding the exact pressure levels that DSOs will be able to operate at [18].

Based on the pressure requirements, three groups were identified in terms of local gas infrastructure: regional low pressure gas grids (<16 bar), regional high pressure gas grids (>16 bar) and transport by tube trailers (see Table 10).

Table 10. Overview of pressure requirements for planned local gas infrastructure.

	Project	Pressure in grid (bar)	End-user	Pressure at end-user (bar)
Regional low pressure gas grids (<16 bar)	Bolsward	3	Industrial burners	0.003
	H2GO	8	Heating houses	0.003
	H2avennet	16	Industry	Varies
	GROHW	16	Industry / mobility	Varies
Regional high pressure gas grid (>16 bar)	Duwaal	40	Mobility	350 to 700
	Agriport A7	Adapt to backbone	CHP	-
High pressure tube trailers	H2 Hollandia	500	Likely mobility	350 to 700
	Zephyros	-	Mobility	350 to 700
	Hessenpoort	-	Mobility	350 to 700

Regional low pressure gas grids (<16 bar)

For the built environment and most industry applications (e.g., heating/drying) low pressures can be applied, typically around the same pressures as those used for natural gas. This means that for such applications, a pressure in the grid of max 8 bar would be satisfactory (as seen in Bolsward and H2GO projects). For other applications the desired pressure is typically higher. For example, chemical companies and feedstock applications typically require >8 bar and in some cases even >20 bar and mobility off-takers require as high a pressure as possible, but at least >10 bar to prevent excessive compression costs. Besides the pressure requirements for the off-takers, other factors can also be of importance for designing a local distribution grid. For example, a higher pressure in the gas grid also offers higher capacity within the grid and ensures a stronger business case in the future (e.g., H2avennet – higher than 8 bar but lower than 16 bar). Another important factor for designing the pressure of the local gas grid is the regulation that describes which pressures the DSOs are allowed to handle. For example, the GROHW project considered a higher pressure grid up to 40 bar but since Firan was not allowed to handle such pressure it is likely that the grid will be max 16 bar. The choice for a grid of max 16 bar was also made to keep the time required to get a permit as low as possible.

Regional high pressure gas grids (>16 bar)

DSOs are not involved in the regional high pressure gas grids due to the regulations preventing them to handle gas above 16 bar. In such cases a private DSO structure can be applied, in which the private DSO is free to handle the hydrogen grid at the desired pressure. For example, in the Agriport A7 project, the pressure in the ECW grid would be similar to the pressure in the hydrogen backbone in order to be ready to connect in the future (after 2030). In the Duwaal project, the hydrogen pipeline will be at least 40 bar (and could go even up to 80 bar) to prevent depressurizing and later pressurizing again the hydrogen for mobility end-users. Another reason for this high pressure in the pipeline for the Duwaal project is that they not only see the pipeline as a means of transport, but also as a means of storage; when using composite pipelines instead of steel pipelines (which are typically used for the existing natural gas grid) an interviewee of Soluforce mentioned that the hydrogen pressure can easily be increased or reduced without the risk of pipeline fatigue.

Transport by tube trailers

Several projects (initially) plan to use tube trailers for transport rather than constructing a regional hydrogen pipeline. The H2 Hollandia and Zephyros projects both expect in the initial phases that the end-users will be in the mobility sector and supply their hydrogen therefore at high pressure by tube trailers. The Zephyros project aims to scale-up and considers a local hydrogen network and connection to the backbone at a later stage. The Hessenpoort project also initially plans to use tube trailers. If the project will be scaled up, ideally it will be connected to the hydrogen backbone and otherwise local infrastructure needs to be built since the supply would become too large for tube trailer transport.

4.4.2 Quality

In general, most off-takers (such as industrial burners, built environment and combustion engines) do not require very high quality and the quality expected from the backbone (98 – 99.5%) will be sufficient (see Table 11). The hydrogen used in fuel cell (e.g. for mobility and back-up power) and industrial feedstock applications in particular requires high purity hydrogen. In all projects an electrolyser is planned as the source for generating hydrogen (except for H2avennet in its early standalone phase, where hydrogen will be produced using biomass, and electrolyser production and hydrogen imports will follow in the future). This means that the purity of hydrogen in all the local grids with new pipelines will be 99.9% and in tube trailers will be fuel cell-grade. If, at a later stage, a connection to the backbone is made, challenges arise for end-users which require high purity (e.g., mobility >99.9%).

Additionally, at this moment it is unclear if an odorant will need to be added and if so, which odorant will be added and is, or has been, a challenge facing certain projects (GROHW, H2avennet). The presence of an odorant will also affect the purity of hydrogen and it may need to be removed (especially if it is a sulfur-containing odorant) to achieve the purity required for fuel cells. H2avennet stakeholders expressed that the odorant to be used in their network remained uncertain in earlier phases of the project and emphasised that it would have been easier if, early in the project, a standardised decision from Netbeheer Nederland would have provided clarity for off-taker contracts. However, this barrier is currently solved, because it has been decided that THT will be used as odorant in this network. For GROHW, it could also help to determine whether a different odorant will be needed for Nefit-Bosch (since they will need to test equipment using UK standards) and make plans accordingly in their network.

Table 11. Overview of quality required from the end-users of the different projects.

Project	Planned end-user (short term)	Quality required from end-user
Agriport A7	CHP	99%
Bolsward	Industrial burners	95%[a]
Duwaal	Mobility	>99.9%
GROHW	Industrial burners, mobility	>99.9%
H2 Hollandia	Likely mobility	>99.9%
H2avennet	Industry	Varies[b]
H2GO	Heating houses	95%[a]
Hessenpoort	Mobility	>99.9%
Zephyros	Mobility	>99.9%

[a] Not specified in interview, but 95% is typically sufficient for combustion processes. [b] There are various off-takers foreseen and the required hydrogen quality varies from relatively low (95%) for combustion purposes to high (>99.9) for feedstock applications.

It is at this moment unclear who will be responsible for the required purification step, but two possibilities were suggested: i) purification should be done by the grid operator (either local or HNS) as this would only require one purification unit for multiple off-takers. The off-taker that requires high-purity hydrogen would pay an additional fee for the purification step. ii) Purification should be done by the off-taker that requires high-purity hydrogen. However, the investment costs of a purification unit would be very high for a single off-taker. These high costs can have an effect on the design choices of the projects. For example, the Agriport A7 project originally considered fuel cells for the backup of the datacentre. However, since the expected quality from the future backbone connection would not be high enough, it is considered that a combined heat and power plant (CHP) might be more suitable to provide the backup in order to prevent the additional CAPEX for purification of hydrogen.

4.4.3 Volumes

In general, most projects start at a small scale, typically 5 MW or less, and have plans to scale-up in the future (Agriport A7, Zephyros, Hessenpoort, Bolsward, GROHW, see Table 12). The expected scale-up size is typically up to 30 MW (Agriport A7, Hessenpoort, Bolsward, GROHW). The driver behind upscaling differs between the projects. For example, in the Zephyros project the electrolyser producer has ambitions to develop an electrolyser of approximately 200 MW mainly to feed in the backbone in the future. The Bolsward project starts with a 5 MW electrolyser and plans to build it up to 25 MW within three years to be exempt from the additionality principle of the RED delegated act. Additionally, it is easier to start at a small scale and build up the demand market, because at this moment they have enough industrial demand for 5 MW but not yet for 25 MW. The scale-up phase was also cited as a way to attract investment in the project by building interest around an operational and growing initiative.

Table 12. Volumes expected for first phase, scale up phase and when a potential backbone (BB) connection is realised.

Project	Capacity first phase	Capacity scale up	Capacity after BB connection
Agriport A7	5 MW	14 MW	-
Bolsward	5 MW	25 MW	-
Duwaal	5 MW	-	-
GROHW	50 kw pilot, then 2.5 MW	30 MW	-
H2 Hollandia	5 MW	-	-
H2avennet	55 MW	500 MW	-
H2GO	2 MW	-	85-100 MW
Hessenpoort	0.85 MW	10-15 MW	-
Zephyros	2 MW	-	200 MW

The Hessenpoort and GROHW projects started with a pilot project and plan to further increase the size in the future. Hessenpoort started their demo a bit smaller (0.85 MW) than expected (1.3 MW) due to a limited electricity grid connection. They foresee a max of 10-15 MW production of hydrogen in the future, bases on the oxygen demand of the wastewater treatment plant. GROHW has realized a pilot phase of 50 kW and is now preparing for the next phase which is a 2.5 MW electrolyser (which is smaller than the originally planned 5 MW due to limited grid connection) and a final phase up to 30 MW capacity based on the local industrial demand.

The H2avennet project stands out due to its size. Already in the first phase a 55 MW hydrogen production from biogas is expected. There are plans for the future to add electrolysis and to import hydrogen, with a total hydrogen supply of about 500 MW. Zephyros similarly has large scale-up potential once the backbone is connection is realized. It is notable that both projects are located in harbour areas anticipated to be offshore wind landfall locations.

The only project that currently does not have plans to scale-up is the H2 Hollandia project with a scale of 5 MW. This scale is perceived as an optimum based on the production capacity from the connected PV park, the surplus of energy, the grid connection capacity and the spatial aspect of the location.

4.5 Impact of electricity grid congestion

In short, congestion can be a major barrier for standalone hydrogen project development when a grid connection is needed for the electrolyser. On the other hand, standalone projects demonstrated innovative ways of reducing electricity grid size needs, sharing grid connections, and providing local balancing in order to cope with congestion issues.

Electricity grid congestion is a continuously increasing issue in the Netherlands, both for the off-take and feed-in of electricity, though the severity of the issue depends on the geographical location (see Figure 15). It is thus not surprising that a few projects (GROHW and Hessenpoort) were already impacted by grid congestion. For other projects availability of the electricity grid was not an issue, though in some cases it was perceived that it is likely to become an issue in the future.

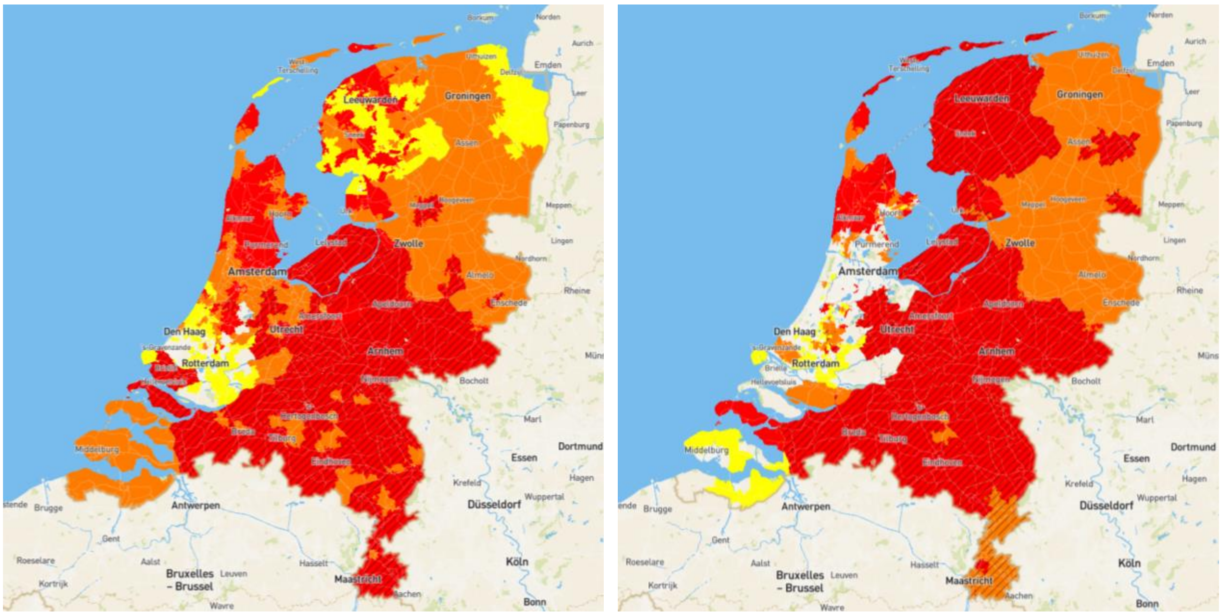

Figure 15. Grid congestion for electricity off-take (left) and feed-in (right) in the Netherlands on 15-02-2024 [4]. Transparent: transport capacity available; yellow: limited transport capacity available; orange: no transport capacity for the time being, waiting on congestion management research; red: no transport capacity available, congestion management not possible; transparently shaded: capacity available if congestion management is applied; yellow shaded: limited capacity available if congestion management is applied; yellow shaded: no capacity for the time being, waiting on division of newly available capacity due to congestion management; red shaded: no capacity available, the limits of the application of congestion management have been reached.

4.5.1 Projects impacted by grid congestion

For the GROHW project, congestion was perceived to be the biggest challenge, as there was no electricity available for the electrolyser at the location where the project was initially planned. One of the off-takers does have some additional electricity capacity available allowing for a smaller-than-planned (2.5 MW rather than 5 MW) electrolyser in the initial phase, but the possibility of future scale up will be fully dependent on when new capacity becomes available in the area.

The electrolyser of the Hessenpoort project was also smaller than originally planned (0.85 MW rather than 1.3 MW) due to grid congestion in the area. Because of the grid congestion, the industrial partners in the Hessenpoort area are in the process of making a collective electricity contract with Enexis. It is also being investigated how the electrolyser can be integrated into the collective platform. With the use of a so called 'steering platform' all electricity that is used and produced is monitored real time and can be balanced, e.g., with hydrogen production, batteries and vehicle loading speeds. This collective platform allows for using the available electricity in a much smarter way, as the partners now have an incentive to work together. For example, the partners are looking at their production process whether it is possible to reschedule certain activities to moments when the capacity is available. Additionally, companies that are now not allowed to feed their overproduction of solar energy into the grid, would be able to do so as long as the total capacity of all partners is not exceeded.

4.5.2 Projects not (yet) impacted by grid congestion

Within other projects it was also underlined that grid congestion is a critical issue for hydrogen production projects, but they were not (yet) impacted by it. For example, the Bolsward and Zephyros projects secured the grid connection capacity that they were aiming for. While the Bolsward project expects their capacity to become 25 MW, there is even some capacity available to further grow the project up to 40 MW.

There is a wide variety of activities planned in the H2GO program, that are affected differently by the grid congestion. For the 2 MW electrolyser planned for the Greenpoint HRS, no problems regarding the grid connection are foreseen due to its small size. Grid congestion is also not an issue for the total of 35 MW electrolyser capacity planned by Van Pallandt since the hybrid electrolysers are connected to a wind park. Thus, the wind energy can be delivered either to the grid or to the electrolysers. The business park Overflakkee has a potential for 50 MW, but this project is still in very early stages. However, it is likely that this project would be impacted by grid congestion due to its relatively large size and the lack of renewable energy production in the vicinity.

The Duwaal and H2 Hollandia projects were not affected by grid congestion because they are connected to their own wind turbine and solar park, respectively. The latter was connected "behind" the PV connection, which is expected to increase PV production yields by reducing curtailment without having to increase the connection capacity. Although grid congestion is a big issue in the area, Agriport A7 was not affected by it because they are connected to their own electricity grid (containing CHP and both solar PV and a wind turbine). Their private grid still has some capacity available and will be further expanded in 2026. This is a big contrast with the local DSO grid, as the turbines located next to the Agriport A7 area already must be curtailed on certain moments due to congestion.

4.5.3 How to deal with grid congestion

There are different opinions on how to deal with grid congestion. For example, in one of the interviews it was mentioned that the solution to grid limitations is to expand the grid, rather than building hydrogen plants to take away some grid congestion, because the interviewee expects this to be cheaper and more efficient. Another interviewee envisions placing electrolysers directly alongside electricity production facilities as the best way to solve grid congestion, not only for new but also for already existing electricity production. However, placing electrolysers next to already existing electricity production sites will not be allowed anymore in the future due to the additionality principle of the RED delegated act. An important tool to incentivize hydrogen production facilities to be located directly next to the electricity producer is to raise the costs of electricity producers to be connected to the grid, so that the cost for suppliers and off-takers would be equal. Yet another interviewee suggests focusing on a mixed energy system since it is not possible to strengthen the electricity grid to the current demand. Because strengthening the electricity grids will also take 10-15 years, the focus should not only be on electrical infrastructure, and molecules will get a bigger role in the future. For example, it is perceived that if there is insufficient electricity available in the mobility sector to charge trucks, hydrogen will get a bigger role in transport. Another approach to deal with grid congestion is by connecting different projects or companies to the same grid connection capacity. This approach was already implemented in the Hessenpoort project and is the planned approach in the H2 Hollandia project as this allows for more effective usage of the current infrastructure.

Within multiple projects, the electrolyser was not originally intended to be used for grid balancing, but they are either open to help or actively looking into cooperation with the DSO or TSO (Bolsward, H2 Hollandia, Hessenpoort, Zephyros). For example, in the Zephyros project, they envision the electrolyser to act as a buffer by producing hydrogen if there is an overshoot of electrical production. A more flexible operation of the electrolyser of H2 Hollandia is also considered in the future, especially if potential opportunities arise, such as compensation for grid balancing services. Hence, there seems to be an opportunity if local electrolysers are stimulated better to partially shave the highest supply peaks in local electricity grids.[7] Especially, when there is a lot of hydrogen demand in the standalone area, or when the standalone area will be connected to the central hydrogen backbone in the future.

[7] See also HyDelta 2 D4.2 where this is thoroughly analysed [19].

5. The potential of standalone hydrogen areas in the Netherlands

In this chapter the more strategic and generalised learnings from the study will be presented and discussed. Namely, a light will be shed on the most prominent enablers and barriers, the general viability and the typologies of standalone hydrogen areas in the Netherlands.

5.1 Cross-case enablers and barriers for standalone hydrogen areas

Table 13. Must-have criteria for viable standalone hydrogen areas

Must-have criteria for standalone areas	Relevant Projects
Favourable off-take conditions	All projects (varies) – see section 5.1.2
Coordination	All projects (varies) – see sections 4.1 and 5.1.3
Availability of hydrogen through import or local production. For local production, availability of green electricity (either via sufficient grid connection or direct integration of renewables) is an additional must-have.	Key enabler or barrier identified by most projects – see section 4.5
Subsidy funding	Key enabler or barrier identified by most projects
Government support (particularly for permitting but nice for other aspects)	Key enabler identified by most projects – see section 4.1.1

Table 14. Nice-to-have criteria for viable standalone hydrogen areas.

Nice-to-have criteria	Relevant Projects
Synergies (waste heat and oxygen)	Hessenpoort, Agriport A7, Bolsward, GROHW – see section 5.1.4
Scale-up phase	Almost all projects – see section 4.4.3
Backbone timeline clarity	Agriport A7, Bolsward – see section 5.1.1
DSO Involvement	Varies by project – see section 4.1.2
Geographic concentration of demand	Bolsward, GROHW, H2avennet

Many enablers and barriers across cases were not unique to standalone hydrogen projects but characteristic of any hydrogen development. For example, common enablers include favourable permitting conditions, adequate grid connection capacity for the electrolyser, securing large subsidies, and strong government and public support. Some frequently cited barriers include the notorious “chicken and egg” problem of getting all parties to reach FIDs, relatively high (or still unknown) green hydrogen prices, government regulations and legislation (e.g., RED delegated act), grid congestion, and high reliance on subsidy funding. The following findings highlight some notable takeaways, which are of particular relevance to standalone areas and more pertinent to the focus of this report:

- Backbone-related enablers and barriers (5.1.1)
- Off-taker-related enablers (5.1.2)
- Communication and coordination-related enablers (5.1.3)
- Enablers relating to synergies between hydrogen, heat, and oxygen off-takers (5.1.4)

5.1.1 Backbone-related enablers and barriers

Dealing with uncertain HNS connection timelines and feelings of a general lack of transparency from HNS is common through many projects.

Stakeholders involved in the Bolsward and Agriport A7 projects alluded to the fact that while in the past there seemed to be clarity from HNS, the timeline and process now seem much more uncertain. While both projects are proceeding amidst this uncertainty, having a clear timeline would prove helpful to planning their current infrastructure investments. *"We know that the backbone is running nearby Bolsward … But how the process is going within Gasunie (if it's going to be there, when it's going to be there, if we can get make a connection). Three years ago everything was, 'yeah you can make connection if you just do it in this these terms,' and now everything is more behind doors and we don't know exactly what's going on … We don't need the backbone connection, but it's nice to know when it comes (if it comes) so we can take it in account in our business case" (Project Coordinator – Bolsward).* For Agriport A7, a backbone connection would be the simplest solution, but there is a feeling of being "*at the end of the line*," when it comes to getting an HNS connection, thus serving as an impetus for starting with a small-scale standalone hydrogen area system in the near-term.

In multiple cases, plans for full scale-up or 100% transition to hydrogen by industry off-takers will require a backbone connection in the future to provide the large volumes demanded and the degree of security of supply required (Agriport A7, Bolsward, GROHW). In these examples, standalone areas are proceeding amidst these uncertainties but would stand to benefit from a clear timeline of when (and if) they will receive an HNS connection to inform current infrastructure investments.

5.1.2 Off-taker-related enablers

Enablers relating to favourable off-take conditions were the most common category of enablers mentioned across cases. Although the importance of off-take is not unique to standalone areas, it was evident from interviews that having the **right** off-taker is of particular importance to standalone areas. For instance, H2 Hollandia will employ a distributor model with one key entity being responsible for handling storage, transport, and off-take contracts for all hydrogen produced by the system. The project manager explains that despite considerable interest in participating, many off-takers were easily excluded, as they did not fit the profile of off-taker that was demanded by the project context. *"You do not only want a party that's interested in the hydrogen, but you want a party that is actually able to organize and mobilize this off-take capacity … to make sure that they're big enough and they can cope with these variability issues. (Project Manager – H2 Hollandia).*

It was clear that the archetype of the ideal off-taker varied from case to case. For instance, the Bolsward project coordinator emphasised that standalone areas should have demand from off-takers that are "*not [too big], not [too small], just the right size*," such that they have both the capacity and motivation to take the first steps. They should have larger hydrogen ambitions as a company and be "*clever*" enough to understand the value of alternatives to natural gas in anticipation of future price increases from changing EU ETS guidelines, for example. In fact, it is perceived that if any of these key off-taker characteristics are missing, a standalone area might not be feasible: *"It's not for every city … for Bolsward, it is very interesting because we have the parties which **want** to get off natural gas" (Project Coordinator – Bolsward).*

A summary of other key off-taker-related enablers that were identified across cases can be seen in Table 15.

Table 15. Favourable off-taker characteristics identified as enablers in stakeholder interviews.

Favourable Off-Taker Characteristics	**Projects with one or more relevant off-takers**
Off-takers with higher willingness to pay (WTP) to ensure reliability of supply or because alternatives are not feasible (e.g., electrification)	Agriport A7, H2avennet, Bolsward, GROHW, Zephyros
Off-takers with higher WTP to benefit from a "greener" image	Agriport A7, H2avennet
Off-takers with higher WTP given a sustainable alternative will enable continued business growth in the Netherlands	Agriport A7
Off-takers with higher WTP because they can be partial owners in their energy supply, thus part of a strategic investment	Bolsward
Off-takers with broader hydrogen ambitions as a company	Bolsward, H2avennet
Off-taker accepts variable hydrogen pricing based on electricity price (key to finalising off-taker contracts)	H2 Hollandia
Off-taker accepts constant price for project duration (key to secure project financing)	Hessenpoort
Off-takers able to deal with variable supply of green hydrogen (through blending of natural gas or grey hydrogen for industry or by finding alternate forms of supply for mobility)	Bolsward, GROHW, H2avennet, H2 Hollandia
Off-takers with an "*entrepreneurial mindset*" (perceived to be less risk averse)	Greenpoint HRS (H2GO), Hessenpoort

5.1.3 Communication and coordination-related enablers

Enablers related to communication and coordination were among the most common of those mentioned in stakeholder interviews. While this might seem intuitive and not unique to standalone hydrogen areas, such coordination efforts can mitigate many of the distinct barriers that decentral projects face (Table 16).

Table 16. Coordination-related mitigation measures for addressing barriers common in standalone areas.

Common barriers to standalone hydrogen areas	Coordination-related mitigation tactics mentioned by case study areas
Decentral areas have many stakeholders involved and difficult to get them all in line	Having a single entity dedicated to coordination of the value chain
Newness of standalone areas results in many unforeseen obstacles during project development	Committed effort to learn from previous projects (or from pilot stages) and share insights for development of future projects
Subsidy funding is limited but critical for standalone area development before hydrogen market reaches maturity	Coalition building and coordination with NGOs and knowledge institutes can help unlock subsidies
Challenges facing standalone areas are diverse and unique (technical, regulatory, financial, etc.)	A broad coalition of stakeholders can navigate challenges by leveraging respective areas of expertise
Newness of hydrogen can lead to concerns about its feasibility and safety	Proactively engaging with off-takers to demonstrate potential uses of hydrogen to bolster support and engaging with community members and local regulatory bodies to discuss safety concerns
Standalone hydrogen areas require continued long-term support from a wide range of stakeholders in the face of repeated hurdles	Commitment to communicating the broader societal benefit of the project to boost support and keep stakeholders engaged

5.1.4 Enablers relating to synergies between hydrogen, heat, and oxygen off-takers

Finding opportunities for synergies between off-takers of hydrogen, waste heat, and oxygen was a notable enabler across multiple case study areas (Hessenpoort, Agriport A7, Bolsward, GROHW). For some, it was perceived to be of fundamental importance: *"I think every spot whether there are **real chances for system integration** … [is] a very good starting point to look at small-scale local standalone hydrogen production. **Maybe it's the only good reason**. When you have no chances for system integration, then you better scale it up and look only to the big production spots for hydrogen" (Hessenpoort).* The datacentre off-taker for the Agriport A7 project expects that small-scale production will only play a role in certain cases, especially when there is a local heat off-taker to improve the economics of the decentral electrolyser business case.

For other projects, such synergies were deemed important, but not critical. For instance, the coordinator of the GROHW project asserts that opportunities to utilise waste heat and oxygen between concentrated off-taker parties can be one of the many criteria *"influencing the likelihood of starting a project."* Meanwhile, the project manager for Bolsward acknowledged that the utilisation of oxygen will be helpful for the business case but is not vital.

5.2 Viability and potential of standalone hydrogen areas in the Netherlands

5.2.1 Viability based on end-users

The contribution of standalone hydrogen projects in the successful roll-out of hydrogen infrastructure in the Netherlands is discussed based on the three major end-users within the projects: mobility, industry, and built environment.

Standalone projects with mobility end-users are potentially viable. A large advantage of local hydrogen production by an electrolyser is high hydrogen purity (i.e., fuel cell-grade). Thus, while hydrogen supplied by the backbone requires an expensive purification step, such additional costs can be avoided using a local electrolyser. This does not only have a positive effect on the business case of the electrolyser (high quality off-taker has a higher willingness-to-pay compared to lower quality off-taker) but also of the end-user (the investment costs of a purification unit are very high for a single off-taker). Furthermore, hydrogen demand in the mobility sector is relatively stable throughout the year and, therefore, the required storage capacity is relatively low compared to sectors with a larger seasonal variability. However, lack of commitment to hydrogen from potential off-takers in the mobility sector due to the high hydrogen prices presents a significant challenge for the business case.

Standalone projects serving industrial off-takers of hydrogen are likely viable, but only to a certain extent. In all of the cases, at least a part of these industrial off-takers are typically quite flexible as they replace only part of their natural gas or grey hydrogen demand. This flexibility stimulates local hydrogen grid development. However, this means that not all industrial end-users do plan to completely fulfil their natural gas demand with locally produced hydrogen due to the low security of supply compared to that of natural gas. Only when they will be connected to the backbone will they fully commit to hydrogen in their system.

A standalone project with built environment end-users only will likely not be viable. The main reason is that a dedicated electrolyser for built environment is always challenging due to the difference between the production profile of the electrolyser and the demand profile of the consumers. The seasonal imbalance requires either significant hydrogen storage or a large electrolyser that only very rarely is required to run at full capacity, both of which significantly increase the cost of the project. Additionally, a high security of supply is required in order to maintain warm houses even during a cold winter which requires additional storage capacity. Note that for the built environment end-use described in this research, the H2 pipeline is a repurposed natural gas pipeline and, therefore, natural gas cannot be used as a backup in case of severe winters. In situations where the H2 pipeline is installed additional to the natural gas pipeline the viability may improve.

Some of the standalone areas foresee multiple end-users in the future, which may lead to synergies between different types of off-takers. For example, the business case for an electrolyser with industrial off-takers was envisioned to be strengthened if an additional mobility off-taker can be found due to the higher willingness-to-pay for H2 in mobility compared to industry. On the other hand, the business case for an electrolyser with only a mobility off-taker (which has relatively low H2 off-take) can also be improved by adding industrial off-takers. This will require a larger electrolyser and decreases the production costs of H2 per kg due to the economies of scale. The synergies between off takers in a region can also be utilized when a region opt for a backbone connection.[8]

[8] For this synergy, the reader is referred to chapter 5.3 in HyDelta 1 D7A.2 [2].

5.2.2 Role of backbone connection in viability of standalone projects

In most standalone projects, a connection to the hydrogen backbone is anticipated in the future and these projects are often only deemed viable if this connection will be established. Considerations regarding security of supply were often perceived to be key in determining the feasibility of standalone areas. For instance, one member of the H2avennet project (which will likely be standalone only in its initial phase) expressed that off-takers with existing grey hydrogen demand that can blend green hydrogen in flexible amounts can make dealing with security of supply easier before a backbone connection is realised. An equipment supplier for the Duwaal project explained that stability in supply of hydrogen in standalone areas can be dealt with by having multiple sources of production or preferably local storage, but ultimately *"it's always good to have the backbone as your balancer,"* casting doubt on the future feasibility of standalone areas without HNS connections.

Nevertheless, the Bolsward, H2 Hollandia, and Hessenpoort projects can be considered truly standalone; they are not specifically waiting for, or relying upon, a backbone connection for their planned hydrogen production. These projects indicate that standalone projects can be economically viable, as they expect a positive business case if support is received.

5.2.3 Relevance of standalone projects further away from the backbone

The standalone projects discussed in this research are typically located or planned in close proximity to the hydrogen backbone, with the exception of the H2GO program. Initiatives located further away from the backbone can contribute to build local hydrogen demand large enough to apply for a backbone connection, and to test the suitability of hydrogen application for interested end-users, before making the FID for the relatively expensive backbone connection. Nevertheless, standalone projects located further away from the backbone are perceived to be more challenging, in particular in terms of security of supply. A business developer at Firan contends that standalone areas away from the backbone could be feasible only if located near a bunkering facility with adequate storage to accept import volumes large enough to deal with security of supply. This view was echoed by a former OEM supplier for H2GO, who was sceptical of the role that standalone areas with local electrolysis will play in a country as small in the Netherlands, and suspects that local cracking could be a preferred alternative when a backbone connection is not feasible.

5.2.4 Costs of small-scale locally produced hydrogen vs large-scale centrally produced hydrogen

Local production of hydrogen is perceived to be very expensive, and in some cases, interviewees expressed the sentiment that small-scale production does not make sense. For example, *Hydrogen production is expensive and the smaller you make it, the more expensive it gets. I know that I have a very small electrolyser … and [if] I make it 50 times bigger when it comes to capacity … the costs [will be] only three times more expensive" (Stedin – in reference to another pilot in which they are involved).* However, others expect that competing with large scale centralised electrolysers will be particularly difficult in the starting phase but expect it to be competitive in a later stage. After running the electrolyser for 10-15 years, the investment costs have been written off and the biggest costs in the business case is the procurement of electricity (about 70%), which is expected to be competitive: "*So if you can compete with those guys at the same windfarms or whatever they are interested in, you can make the same deals, so to say. And maybe with a better story than them, you can get a little bit of reduction in prices" (Project Manager – Bolsward).*

5.2.5 Note on economics of standalone areas

The standalone projects can be divided into two groups: pilot or demonstration projects, and commercial projects (Table 17). The pilot and demonstration projects are typically small-scale projects that are focused on learning best practices or intend to enhance the roll-out of specific technologies or develop blueprint systems (e.g., flexible composite pipeline or hydrogen bunkering stations for shipping), and do not necessarily require a positive business case. Other projects are intended to be commercial and were able to come to a positive business case. However, it must be noted that all projects currently rely heavily on subsidies and without these financial support measures even the commercial projects are unable to come to a positive business case. In the end, "it *will be successful … the moment that we don't need any funding from being subsidized"* (*Communications advisor – GROHW).*

Table 17. Overview of pilot or demonstration projects and commercial projects.

Pilot or demonstration projects	Commercial projects
Duwaal	Agriport A7
GROHW pilot phase	Bolsward
H2GO Stad aan 't Haringvliet	GROHW final phase
Zephyros	H2 Hollandia
	H2avennet
	H2GO Greenpoint HRS
	Hessenpoort

5.3 Typologies and building blocks of standalone hydrogen areas

Now that the viability of standalone hydrogen areas is discussed, this chapter reflects on the findings and describes what types of standalone hydrogen areas are seen and can be expected to develop. Typologies can be made on a lot of characteristics, such as distribution of roles, government involvement, or key drivers. Many of such categorisations have been described in chapters 3 and 4 already. In this chapter the main typologies in physical design of standalone hydrogen areas are presented.

Although every standalone hydrogen area was seen to have its unique story and drivers, two physical standalone hydrogen typologies can be distinguished. These are mainly determined by the hydrogen source and the hydrogen off take in the regions. The first differential factor is whether the hydrogen is primarily consumed by fuel cell applications or other applications. The second differential factor is whether hydrogen is sourced by local electrolysis or other means. Table 18 summarizes the investigated cases based on these two factors and showcases the four categories of standalone hydrogen areas.

*Table 18. Standalone hydrogen area physical design typologies based on two differential factors. *The Bolsward, GROWH and H2GO projects are not primarily meant to serve fuel cell applications. But some local parts of these standalone areas that are focussed on fuel cell applications (e.g. the HRS) have quite similar characteristics of the standalone areas that are primarily developed to serve fuel cell applications. **Agriport A7 is considering combustion in CHPs in lieu of fuel cells but this remains uncertain.*

H2 source / H2 Off take	Primarily fuel cell applications	Primarily other applications
Primarily local electrolysis	• Agriport A7** • Duwaal • H2 Hollandia • Hessenpoort • Zephyros[9]	• Bolsward* • GROWH* • H2GO*
Primarily other sources		• H2avennet

The first category are standalone hydrogen areas primarily sourcing the hydrogen from a local electrolyser for fuel cell applications. Often, these are relatively small-scale projects located either on one site or on multiple sites connected via tube trailer transport. The Agriport A7 project is somewhat of an exception due to it being a larger scale than a typical HRS. Because of the very high pressure and purity requirements of fuel cells and relatively high pressure and purity output of the electrolysers, maintaining these hydrogen conditions between supply and demand is essential for economics and efficiency. The systems can be balanced by high pressure storage tanks and the tube trailers because of the small volumes and lack of seasonality.

The second category are standalone hydrogen areas primarily sourcing the hydrogen from a local electrolyser to supply applications other than fuel cells, which are in most cases industrial burners. Because industrial demand consists of high volumes, hydrogen is often foreseen to be blended behind the meter in specific burners that allow 0-100% hydrogen blends. Balancing is possible by falling back on natural gas if there is no supply, and therefore often new (additional) hydrogen pipelines are considered next to the existing natural gas pipelines and connection. In addition to natural gas burners, a similar approach was foreseen in pilots for other applications, such as blending local green hydrogen into existing grey hydrogen applications, CHPs fuelled by natural gas-hydrogen mixes, and combustion engines fuelled by hydrogen-diesel mixes.

The third and fourth categories are standalone hydrogen areas that source hydrogen primarily from sources other than local electrolysis. H2avennet was the only selected project that primarily will source biomass-based hydrogen in its initial phase (and plans scaling up with LOHC and liquid H2 terminals and an electrolyser). This method of hydrogen production, or by importing hydrogen (carriers) via ships, inland barges, and rail, can provide large volumes of hydrogen to a standalone area. In many cases, such volumes exceed those that could be feasibly achieved with local electrolysis, which is often constrained by the availability of local electricity and the variation in supply. Nonetheless, blending hydrogen into existing grey hydrogen and natural gas streams was perceived to be a must in the H2avennet project, due to security of supply considerations. Thus, this type of standalone area might also warrant new additional hydrogen infrastructure alongside existing fossil infrastructure. An example of a standalone area with fuel cell applications and without local electrolysis might be the HyNoCa project in Alkmaar (not included in this research) or a mobility hub with multiple customers

[9] Zephyros is unique in the sense that next to fuel cell mobility applications, also combustion engine mobility applications are considered where hydrogen and diesel can be blended as fuel for offshore vessels. This causes that this project has some characteristics related to projects serving other applications.

importing hydrogen (carriers) from elsewhere, but not many of these systems are under serious consideration at this moment.

Table 19. Summary of main design characteristics per standalone hydrogen area typology

Standalone hydrogen area design typology	Volume	Pressure	Quality	Balancing	Transport in area
Local electrolysis and fuel cell applications	Small	High	High	Off-take and storage	Tube trailers
Local electrolysis and other applications	Large	Low	Low	Blending	New (extra) pipeline
Other hydrogen sources and other applications	Large	Low	Low	Blending	New (extra) pipeline
Other hydrogen sources and fuel cell applications	Unknown	High	High	Unknown	Unknown

As mentioned earlier, these typologies are based on the two factors that were found to be most decisive in the physical standalone hydrogen area design. It is important to note that in reality, each standalone area is situated in its own unique context that can further illuminate the course of its development. Moreover, some of the larger standalone areas possess characteristics of multiple typologies, as they involve both fuel cell and other applications. In such cases, where multiple hydrogen sources and off-takers are present, characteristics of multiple typologies can be observed in different subsystems of the standalone area in question.

Given the heterogeneity of standalone areas, identifying relevant building blocks of each can be more informative than one-size-fits-all typologies. Figure 16 demonstrates how different hydrogen sources and applications impact decisions regarding technical characteristics, system balancing, and selected transport modes in (specific parts of) the system. In addition, it sheds light on a key building block, which can be described as the utilisation locational circumstances, for instance: harnessing the by-products oxygen and/or heat of the electrolyser; making congestion issues part of the business model; and importing hydrogen (carriers) via nearby rivers and inland ports (which has been identified as a future opportunity for standalone hydrogen areas).

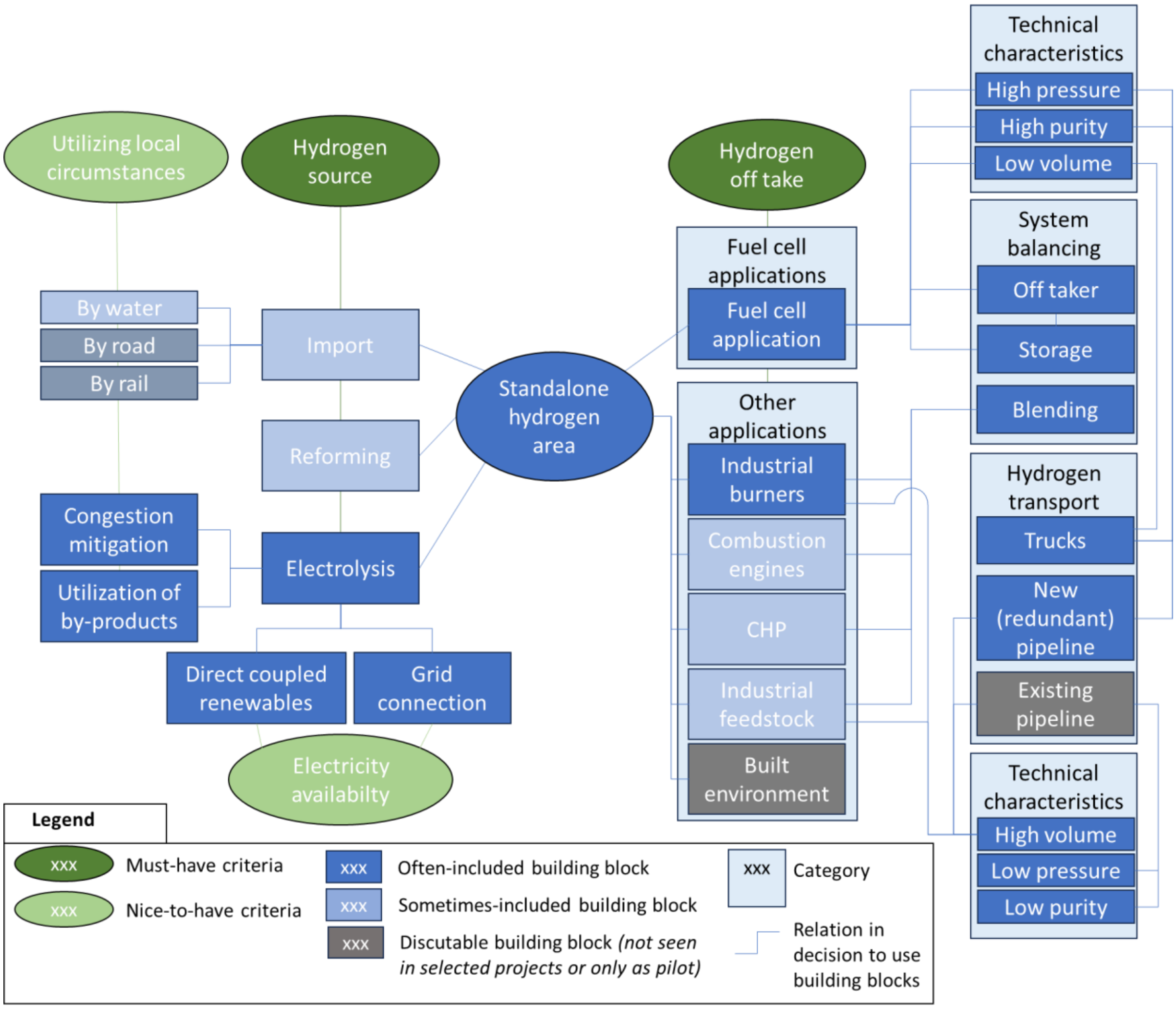

Figure 16. Overview of building blocks of standalone hydrogen areas.

6. Conclusions

Nine standalone hydrogen areas were selected from approximately forty potential standalone areas to investigate how such areas can contribute to the successful roll-out of hydrogen infrastructure in the Netherlands. Semi-structured interviews were held with stakeholders from each of these projects and the obtained information was used to distil cross-case insights and to evaluate the potential and viability of standalone hydrogen areas.

The case study results made clear that every selected project has a unique background and set of conditions that influenced its decisions and developments. Some examples of the factors motivating these hydrogen projects to develop without a pipeline connection to the backbone (at least initially) include the following: decentral off-takers demanding hydrogen and/or availability of renewable electricity; local governments and ports striving to keep their areas attractive; leveraging potential synergies (e.g., heat and oxygen demand) in the region; and learning and demonstrating certain hydrogen value chain concepts and technologies. Detailed analysis of current standalone hydrogen projects was hoped to provide a framework for designating geographic areas in the Netherlands where such activities might have the best chances of success in the future. However, the observed drivers were often intangible and unquantifiable (e.g., motivations of local entrepreneurs or municipal government strategies) and moreover incredibly case-specific, thereby making it unfeasible to use them to spatially identify suitable regions for future standalone developments.

Despite the distinctiveness of each case and its respective drivers, the decision to pursue a standalone system often arises from a reluctance to wait for centrally connected hydrogen infrastructure to become available. This is especially the case for larger scale and/or industrial hydrogen applications. It is perceived viable to start (partial) green hydrogen usage in such processes before a backbone connection is realised, but in all investigated cases at least some customers maintained a connection to the back-up of the fossil system (e.g., via flexible blending of hydrogen and natural gas in industrial burners 'behind the grid connections'). Therefore, in such areas it should be considered that the existing natural gas grid and most of its connections should stay in place and the hydrogen should be delivered to the initial customers via a new hydrogen pipeline. If local electrolysis is the only source of supply, these standalone areas are often limited to a maximum size of around 30 MW.

Nonetheless, not all cases expressed the need to connect to the backbone and instead perceived a standalone setup could be beneficial even when the option to connect to a broader hydrogen network might exist. This was observed in projects involving very small local electrolysis (1-10 MW) to supply fuel cell applications in mobility. The main reason for this was the expected pressure and purity that would be lost by connecting to a local pipeline system with lower pressure and purity standards. This is an important consideration for regional hydrogen infrastructure design.

Large standalone hydrogen regions, covering a widespread area and/or serving the built environment, seem unlikely when hydrogen is solely sourced by decentral electrolysis. The challenges of balancing hydrogen supply and demand and the limited local availability of electricity (via local sources or grid connection) are among the most important limiting factors. As evidence of this, even the 9 relatively small areas that were investigated often already faced size limitations due to such constraints.

Lastly, all investigated standalone projects need public support to close the business case, not unlike hydrogen projects in general. Most of the standalone projects took measures, or have specific characteristics, which improve their economic viability. However, this study did not perform an economic assessment to compare the economic viability of the standalone setups with each other or with centrally produced hydrogen. This can be considered a topic for further research. A summary of the main research findings can be found in Box 12.

Box 12. Summary of main research findings

1. Standalone projects with **mobility off-takers are potentially viable** (benefit from higher quality hydrogen but heavily reliant on overcoming uncertain demand); **industrial off-take is likely viable** (blending is key and backbone is necessary for full transition); **built environment is unlikely viable** (mismatch of electrolysis production and seasonal demand profiles is a fundamental barrier). Also, synergies of having multiple types of end-users in standalone areas can be utilized.
2. In the long run, a backbone connection is often desired for security of supply, but unclear timeline presents challenges for standalone areas. Also, few cases were seen that are truly standalone and do not opt for a future connection to central hydrogen infrastructure.
3. Four main typologies were found to be most decisive in the physical design of standalone areas based on their primary hydrogen source (electrolysis or other) and the primary hydrogen application (fuel cell or other), with most cases in this research falling under typologies 1 and 2 (primarily electrolysis and fuel cell application; primarily electrolysis and other applications).
4. A distinction can be made between low (<16 bar) pressure regional grids (where a DSO is involved and anticipates similar operating limitations to natural gas) and high (>16 bar) pressure grids (where privately owned pipelines maintain higher pressures for mobility or adapting to the backbone).
5. The purity in standalone areas is typically fuel cell grade but this is challenging for fuel cell end-users when a backbone connection (purity 98 - 99.5%) is foreseen; it remains unclear who should be responsible for the required purification step.
6. Having the "right" off-taker(s) is vital to a standalone hydrogen area's success. For example, those with strong hydrogen ambition as a company and/or willing-to-accept higher or more variable fuel prices.
7. Synergies with waste heat and oxygen off-takers are identified in some cases to be crucial for decentral hydrogen production and in others as nice-to-have, but not vital.
8. There are seven key roles identified in standalone areas: project coordinator; key project driver; municipal government; knowledge sharing & advising body; energy balancer; permit provider; and asset investors and operators. All seven roles are necessary for a potential standalone hydrogen area to be developed.
9. The degree of DSO involvement in standalone areas varies. When involved, their technical expertise and coordination capacity can be vital to effective hydrogen infrastructure roll-out or in dealing with limited electric grid capacity; when uninvolved, it can be seen either as a detriment <u>or</u> an opportunity to operate at pressures above 16 bar.
10. The degree of local government involvement varies but is (at a minimum) needed for obtaining permits. It is often a key driving force and preferably can help navigate economic, legislative, and societal barriers.
11. Regulatory and legislative barriers are experienced in all projects, but the ones named are similar to those faced by hydrogen projects in general.
12. The degree of hydrogen infrastructure roll-out varies: some projects invest in infrastructure to prepare the region for a future HNS connection; others must invest in infrastructure to connect off-takers and producers despite an uncertain connection; and others do not intend to develop regional infrastructure other than a tube trailer filling station or an HRS.
13. The largest scale standalone project that is solely supplied by local electrolysis is expected to be around 30 MW by most of the interviewees, given the limits on local electricity sources or grid connection.
14. E-grid congestion is a major barrier in certain cases (limiting production capacities and/or scale-up potential) but innovative methods were adopted to deal with grid congestion (e.g., collective contracts and smart energy management). Local grid balancing is a potential in some areas but there has been no demonstrable progress to date.

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Appendix I: Abbreviations

Abbreviation	**Meaning**
ACM	Autoriteit consument & markt
CAPEX	Capital Expenditure
CHP	Combined Heat and Power
CSA	Connection Service Agreement
DNV	Det Norske Veritas
DSO	Distribution System Operator
ECW	Energie Combinatie Wieringermeer (Private DSO in Wieringermeer area)
EU	European Union
ETS	Emissions Trading System
FID	Final Investment Decision
GDS	*Gesloten Distributie Systeem* (Closed distribution system)
GW	GigaWatt
HBE	*Hernieuwbare Brandstof Eenheid* (Renewable Fuel Entity)
HNS	HyNetwork Services
HRS	Hydrogen Refuelling Station
LOHC	Liquid Organic Hydrogen Carriers
LOI	Letter Of Intent
MVA	MegaVolt-Amperes
MW(p)	MegaWatt (peak)
NEC	New Energy Coalition
NIMBY	Not in my backyard
OEM	Original Equipment Manufacturer
OWE	Subsidy *Opschaling volledig hernieuwbare waterstofproductie via elektrolyse*
PV	PhotoVoltaics
REACT-EU	Recovery assistance for cohesion and the territories of Europe
RED	Renewable Energy Directive
RNB	*Regionale Netbeheerder* (DSO)
RVO	Rijksdienst Voor Ondernemend Nederland
SHA	Standalone Hydrogen Area
SWIM	Subsidie Waterstof Infrastructuur Mobiliteit
TSO	Transmission System Operator
WDOD	Waterschap Drents Overijsselse Delta
WPF	Wind Park Fryslân
WTP	Willingness To Pay
WWTP	Wastewater Treatment Plant