INVEST-NL REBEL

Green hydrogen import through the port of Amsterdam

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Contact

Dolores de Rooij
Dolores.derooij@invest-nl.nl
Q-Port 3rd floor
Kingsfordweg 43-117
1043 GP Amsterdam

Authors

INVEST-NL

Dolores de Rooij
Willem de Boer
Daniël Akkerman
Jeroen van der Wal
Stephan Falcão Ferreira
Madelon Abbes

Co-authors

REBEL

Hans Biersma
Fien Verheij

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Executive summary

Despite the current national policies, local production of green hydrogen is stalling given the high costs of production and in the longer term constrained by renewables capacity in NW-EU. Imports of cheaper produced green hydrogen in liquid form may offer a viable alternative.

Market overview for green hydrogen

- Current dedicated grey hydrogen demand in the Netherlands amounts to 1.5 Mton centered within 5 industrial clusters and stems mostly from: refining, ammonia and methanol; applications where hydrogen is used as molecule.
- Future demand for green hydrogen is expected to become more diversified with a strong focus on industries that will need green molecules to decarbonize their production processes and the mobility sector which needs to meet European targets as specified in the RED III.
- Several studies show a strong demand for green hydrogen. Depending on the study the expected hydrogen demand in 2040 is estimated to be between ~1 Mton and 4.3 Mton. Ministry of Economic Affairs foresees growth of demand up to 5.8 Mton in 2050 as described in the National Plan Energy (NPE), mainly driven by industry, e-fuels and power generation.
- To stimulate the local production of hydrogen, there are already several national and international commitments, regulations and interventions in place, such as the target for local production in the "Klimaatakkoord", reserved budget in the Dutch climate fund, OWE and IPCEI subsidies and an auction scheme of the EU Hydrogen Bank.
- However, the estimated cost of producing green hydrogen in the Netherlands in the range of €7.6/kg - €13.7/kg is still above the willingness to pay for green hydrogen of many off-takers.

Potential for import of green hydrogen

- Studies indicate that hydrogen production cost in the Netherlands are expected to be ~€4/kg -€11/kg higher in 2030 than exporting countries (Oman, Egypt, Norway, Canada, Brazil, Spain, U.A.E. and Saudi Arabia).
- With transport cost for LH2, LOHC, and ammonia in a range of €1.5/kg - €5.5/kg, the lower hydrogen production cost in countries with favourable conditions for renewable energy show opportunities to drive the import of cost-effective hydrogen.
- Dutch government also expects a growing role for the import of hydrogen in order to meet a growing domestic hydrogen demand due to limited renewables in NW-EU.
- Although import of green hydrogen could offer an important contribution to the energy transition, it currently receives relatively little attention from a national regulatory and subsidy perspective.

The case study for Port of Amsterdam explores the viability for importing green liquid hydrogen and an estimate of the current financial gap and explores potential measures that policymakers and investors can potentially incorporate to close the gap

Executive summary

This case study assumes that an aggregator ensures a balanced off-take profile and secure contracts. Based on selected market consultation, the willingness to pay generally ranges between €3/kg and €7/kg

The value chain for importing green hydrogen in Port of Amsterdam

Exporters, transport, green H2 by ship	• Production outside of NLD • Transport in the form of LH2 or LOHC
Import terminal, conversion, distribution	• Role for PoA and pipeline operators assumed in the case (within NSCA area and towards hinterland)
Aggregator	• **The business case assumes the role of an aggregator which ensures a balanced offtake profile and secure contracts**
Off-takers, B2B	• B2B looking into replacing fossil fuels for green H2 • Industrial heating, raw material producers, alternative fuels
B2C	• B2C which need/want to decarbonize their products • For example: food industry, aviation, cars, fashion
End consumers	• Consumers using products that need to be decarbonized

Focus of the analysis (Import terminal, conversion, distribution; Aggregator; Off-takers, B2B; B2C)

Potential off-takers and willingness to pay

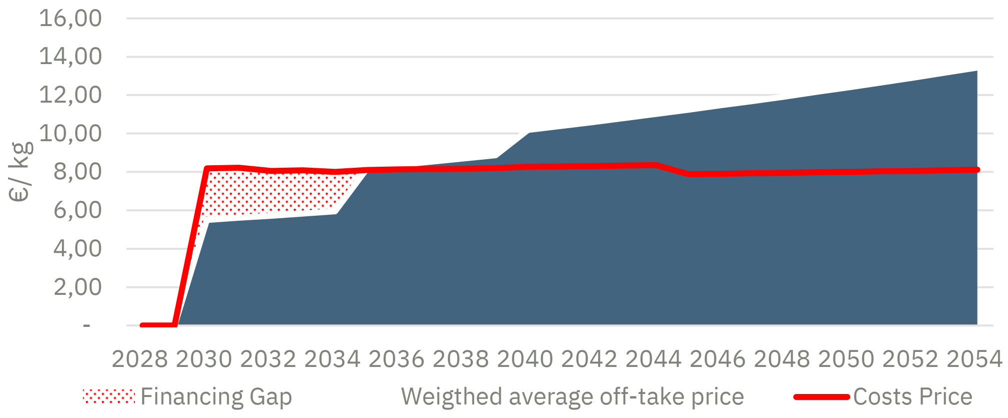
- The port of Amsterdam is well-positioned for potential green hydrogen import due to its attractive position for both local offtake and throughput.
- The projected prices and volumes for each sector highly depend on upcoming regulatory and other governmental incentives. Offtake would be possible for sectors like steel, aviation, heavy duty trucks, (short sea) shipping and other industry.
- The market consultation was comprised of interviews with the consortium (Port of Amsterdam, ECOLOG and Tata Steel), interviews with 8 potential off-takers in or near the NSCA, network operators and a potential aggregator, stating a.o.:
    - The Dutch and German steel sector are both looking into the potential of green hydrogen with its viability highly reliant on the government incentives (to be) provided.
    - Market potential for eSAF is large and incentivized by regulation such as ReFuelEU Aviation, but uncertainty remains around the competitiveness eSAF production in the region.
    - REDIII incentivizes offtake of green hydrogen for transportation and is expected to be most competitive within the heavy-duty market segment.
    - With regulations for other industries still falling behind, demand depends on own initiatives and ambitious goals of industry players themselves.
- Liquid hydrogen imports through the port of Amsterdam could obtain prices between ~€3/kg and €7/kg green hydrogen as this is the estimated Willingess-to-Pay ("WtP")

Executive summary

The business case results in a temporary financing gap at the start of the project, while obtaining a positive net financing surplus over the lifetime of the project. Viability of the project therefore depends on interventions closing the financing gap and addressing the related risks regarding price and offtake

Financing gap

- The business case is driven by multiple factors. Key value drivers of the business case (2030) are a delivered price in the Netherlands of green hydrogen of €8/kg and a WtP in the range of €3/kg - €7/kg in 2030. The business case assumes that the aggregator applies price differentiation amongst off-takers resulting in an average WtP of € 5.5/kg.
- The delivered price of hydrogen (red line) is initially higher than the weighted average offtake price (in blue), leading to a "financing gap". Due to differences in indexation – as well as changes in real production costs and WtP – the average offtake price overtakes production cost in 2042. Over the entire 25-year forecast period, there is a net financing surplus of ~ €1 bn.



Risks to address and possible interventions

1. **Price |** Mismatch between production price and sale price (willingness to pay)
2. **Regulations |** Uncertainty in regulation and other governmental intervention
3. **Offtake |** Uncertainty in offtake green hydrogen (volume and timing)

- Risks 1 and 3 need to be addressed in order to reach FID. Potential interventions addressing these risks could consist of financial products, such as a Capex subsidy, an Opex subsidy, a subordinated loan or a Contract-for-Difference scheme. Regulatory interventions could be another type of intervention. The different types of interventions will likely have a different impact, both from a government perspective as from a value chain perspective.

- A first attempt has been made to rank the potential interventions based on criteria as financial impact, risk mitigation, effectiveness of the financial investment, potential upside (for the government), potential downside and complexity. A **mix of multiple interventions is required and increases the chance to mitigate the different risks**, since they address different risk areas (regulations, financial, market dynamics). First results show a preference for a 2-sided CfD structure in combination with a subordinated loan. However, multiple interventions should be explored.

- Today there are no suitable interventions for the import of green hydrogen as existing instruments focus on local production of hydrogen or have unsuitable funds and tenors. **Future instruments should consider longer tenors, larger budgets, creditworthiness of off-taker(s), and where in the value chain the instrument is applied.**

Executive summary

The performed study shows a potential demand for green hydrogen that can be fulfilled competitively through import if government interventions addresses the financing gap and the identified risks. Further investigation is needed to explore the best suitable solution

Business case considerations: Initial reflections on the business case highlight the significant role of the aggregator given scattered hydrogen demand and the financial gap's sensitivity to the underlying assumptions

- The business case must overcome a substantial financing gap for the first 10 years. Although the existence of the financing gap is certain, the depth and the duration depends on the applied assumptions (the delivered price and the WtP).
- Regulations for different subsectors are likely to impact the base case and may drive the willingness to pay in the future but are difficult to quantify at this stage.
- The offtake potential for green hydrogen through the Port of Amsterdam is only partially reliant on the NSCA. The involvement of an aggregator contributes to the success of the Port of Amsterdam business case managing potential offtake within the NSCA and the scattered offtake potential beyond the area
- In the base case the aggregator provides the necessary commitment to give comfort to financing parties regarding offtake. This assumes required guarantees are provided by the aggregator. Without an aggregator, parties within the value chain will likely require another form of guarantee for volumes and price. Given the large minimum capacity of an import terminal (200 Ktpa) it seems unlikely that this guarantee can be borne by a single off-taker. Hence, additional interventions might be required that may incentivize a specific party or sector.
- In this business case the hydrogen demand is split between the Netherlands and Germany. If and how the financing gap should be split between the corresponding governments is not in scope of this study.

Recommendations

» To mitigate the financing gap, governmental intervention in the form of financial instruments or regulatory requirements are deemed necessary. The choice for the intervention method will depend on multiple factors, including geopolitical, economic and financial ones. The Dutch government needs to assess if interventions focused on (a) specific subsector(s) that are tied to the Dutch economy will be given priority or would prefer an intervention that ensures an overall minimum volume of green hydrogen through the Port of Amsterdam.

» Clarity on impact from regulatory interventions such obligatory targets for the use of green molecules can increase the WtP of off-takers, thereby reducing the need for financial interventions. It is therefore recommended to first take these into account when considering the creation of financial instruments.

» The strategic importance of import of green hydrogen through the Port of Amsterdam will need to be considered within the Dutch Hydrogen Roadmap.

» This study could be exemplary for other import cases within the Netherlands (and/or) Europe. This will need to be assessed.

Section 1:Introduction

Introduction

The case study for the Port of Amsterdam explores the viability for importing green liquid hydrogen and an estimate of the current financial gap and explores potential measures that policymakers and investors can potentially incorporate to close the gap

Green hydrogen is recognized as an important energy carrier for the energy transition, but the development of firm offtake of green hydrogen by the industrial and transport sector has so far been below optimistic expectations, despite the supportive political stance thus far. **The high production costs, the uncertainty in demand policies and infrastructure is creating a barrier for financial parties to become financially involved**. This also holds true for the import case at the Port of Amsterdam, which aims to be an important hub for green hydrogen within the Netherlands and Northwestern Europe.

Invest-NL and Rebel have therefore been asked by the **Port of Amsterdam (PoA), ECOLOG and Tata Steel** to analyze the case for liquid green hydrogen into the Port of Amsterdam and **estimate the current financial gap and explore potential measures** that policymakers and investors can potentially incorporate **to close the gap**.

The report will touch upon the key risks in the import value chain, the current subsidy and regulatory environment, the green hydrogen offtake potential within the area, the contributing role of an aggregator and the potential blended finance solutions.

With the insights into the potential ways to bridge the financial gap (e.g. regulatory changes, supporting policies and well-aligned contract structures) this report **aims to support other import projects within the Netherlands and Europe** as well.

Four stages to completion

The project is delivered through a collaboration between Invest-NL and Rebel in the following phases:

1. Analysis of the available information

a) Assessing the available information
b) Determine what additional information is needed and agree with PoA on timelines for delivery
c) Market consultation and interviews with key parties

2. Illustrate value chain

a) Create illustration of the value chain for renewable hydrogen import
b) Determine key risks

3. Construction of financial model

a) Agree on key assumptions, main drivers and variables of the financial model
b) Build a flexible financial model which makes scenario analysis possible
c) Determine the key value drivers

4. Closing the financing gap

a) Explore potential interventions to close the financing gap
b) Determine the next steps

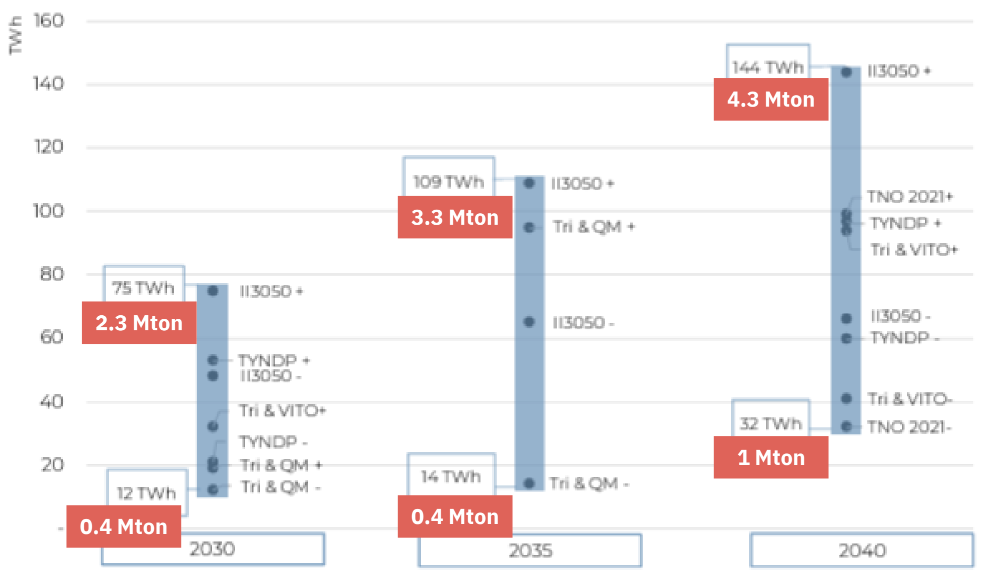
Section 2: Market overview

Dutch Hydrogen Outlook

Import of green hydrogen is an important part of the energy transition with 50% of green hydrogen expected to be imported, but initial subsidy and regulatory focus on local production

- The Netherlands sees hydrogen as an important part of the energy transition and is committed to take the required steps to maintain and strengthen its current position as an energy hub in Northwestern Europe with the import and transit of (green) hydrogen (derivatives)
- Depending on the study the expected hydrogen demand in the Netherlands in 2040 is estimated to be between 1 Mton (32TWh) and 4.3 Mton (144TWh), starting from 1.5Mton today. This is highly dependent on the scenario.
- The Dutch National Hydrogen Programme has created a Hydrogen Roadmap, which gives an insight into the country's ambitions and projections;
  - **Key application sectors for green hydrogen are envisaged to be industry and international transportation** and in a later stage the electricity market (balancing the electricity network, storage) and heating sector.
  - **Up to 50% of the green hydrogen supplied is expected to be imported** (see slide 16), because the electricity production potential from wind and solar energy sources is limited in the Netherlands, the production of green hydrogen in regions with higher potential for renewables is expected to be more economical and the government foresees an important role for the ports in supporting energy hubs.
  - **Initial focus for subsidy and regulation measures will be on scaling up local green hydrogen production** and laying the foundation for the required infrastructure to facilitate the movement of green hydrogen. There are no targets regarding green H2 import in the Netherlands.

Hydrogen demand projections in the Netherlands



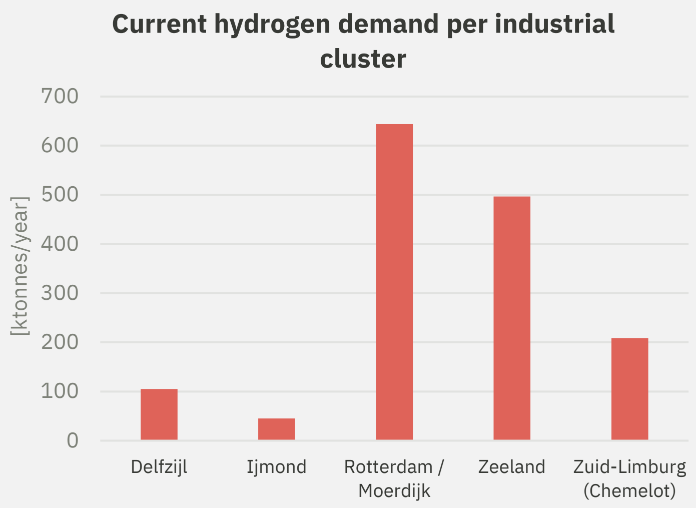
1:Trinomics & Blueterra (2024) 2. TNO (2020) 3. NWP (2022)

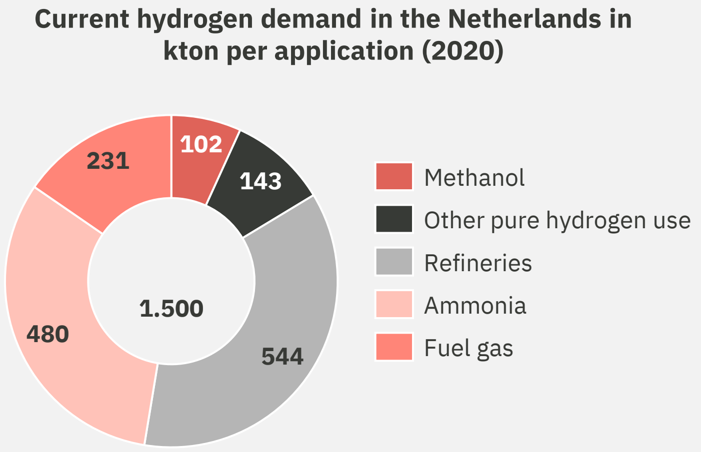
Hydrogen demand landscape in the Netherlands

Hydrogen demand is expected to become more diversified with a strong focus on industry, mobility, and power generation

Current demand applications

Current dedicated grey hydrogen demand is centered within 5 industrial clusters and stems mostly from: Refining, Ammonia, Methanol. Applications where hydrogen is used as a *molecule.*





Based on TNO (2020)

Future additional demand applications

Steel: Hydrogen based directed reduced iron plant to replace coal. Varying blends of natural gas and hydrogen can also be applied in this process

Shipping and aviation: Predominantly production of hydrogen-based e-fuels such as methanol, ammonia, and e-kerosene

Heavy Duty Transportation: Replacement of diesel by hydrogen powered fuel cell vehicles

Power generation: Replacement of gas fired power plants for back-up power generation

Industrial heat: Replacement of natural gas for high temperature heat (150 ºC>)

Key governmental interventions to shape a hydrogen market

There are several commitments, regulations and incentives to stimulate the hydrogen market. Recent work for Invest-NL reveals these have been insufficient to promote investments in domestic hydrogen production[5]

Production

National targets for electrolysis

As part of the Klimaatakkoord in 2019 a national target for 3 – 4 GW electrolysis capacity was set.*

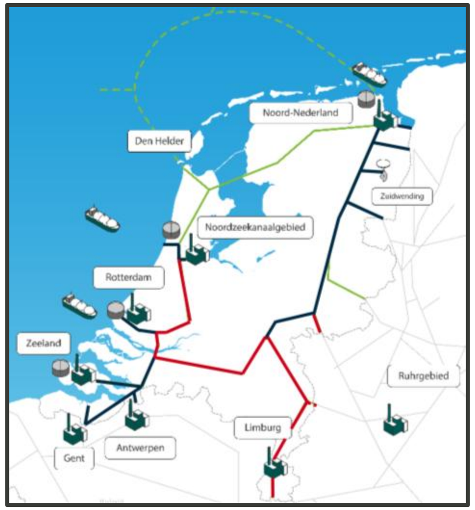
Available production subsidies supporting first hydrogen projects:

- As part of the Dutch climate fund package a total budget of €5.15Bfor onshore electrolysis (50 – 1.000 MW) and €1.78B for offshore electrolysis (<100 – 500 MW) up to 2030 has been announced.[5]
- Opschaling waterstof elektrolyse (OWE): 101 MW in projects in the range 0.5 – 50 MW have been awarded €250M subsidy. In the next round €1B will be granted to projects 0.5MW >.
- Under the Important Projects of Common European Interest (IPCEI) framework The Netherlands has awarded €783M to 7 100-250 MW electrolysis projects.
- EU Hydrogen Bank: EU auction with a susbidy cap per kg hydrogen. In the first round nearly €720M has been awarded to 7 projects in Finland, Spain, Portugal and Norway with bid prices ranging from €0.37 to €0.48 per kilogram of renewable hydrogen produced[6].

Infrastructure

H2 infrastructure rollout to break through the chicken and egg problem

Dutch Government committed €750M to the construction of H2 infrastructure in 2021 by Gasunie. HyNetworks map from July 2023 shows planned development . **Blue 2025 – 2027. Red 2028 – 2029**, **Green 2030 en later**[7]. Note Delta Rhine Corridor (Red West – East connection) postponed to 2032[8].



Demand

EU RED III[9] to drive hydrogen demand

- The EU adopted an amendment of the Reneable Energy Directive, which is referred to as 'RED III'.
- RED III includes a target for member states of at least 42,5% of hydrogen used for energy and non-energy purposes in the industry comes from renewable fuels of non-biological origin (RFNBO) by 2030, and 60% by 2035. However, there still exist uncertainty whether specific industries such as ammonia are included.
- Also, there is a 5.5% target for use of biofuels or RFNBOs by 2030 in the transportation sector with an effective target of 0.5% for RFNBOs.
- Member states have up to May 2025 to implement targets into national legislation.

*4. CommonFutures (2024) 5. Ministry of Economic Affairs (2023) 6: European Commission (2024) 7. HyNetwork (2023) 8. Ministry of Economic Affairs (2024) 9. European Commission (2024a) * No volume target in kton specified by the Dutch government. Around 300 kton can be expected based on 56 kwh/kg total electricity consumption and 4,800 FLH.*

Import is needed to meet demand in 2030 and 2050

Dutch government expects a growing role for the import of hydrogen in order to meet a growing domestic hydrogen demand due to limited renewables in NW-EU

2030 Green hydrogen demand in the Netherlands

Up to 320kton demand from industry and transport driven by REDIII is expected. In the top image this is compared to the current hydrogen demand in the Netherlands. The 2030 RFNBO targets could be realized by ~4 GW domestic electrolysis capacity.* This implies ~50% of the projects under development and expecting to be operational before 2030 are realized.** Despite the growing availability of (production) subsidies, the only final investment decision for sizeable project has been taken by Shell (200 MW). In case certain sectors such as ammonia are exempted from the RFNBO targets, a lower success rate of the domestic projects will suffice.

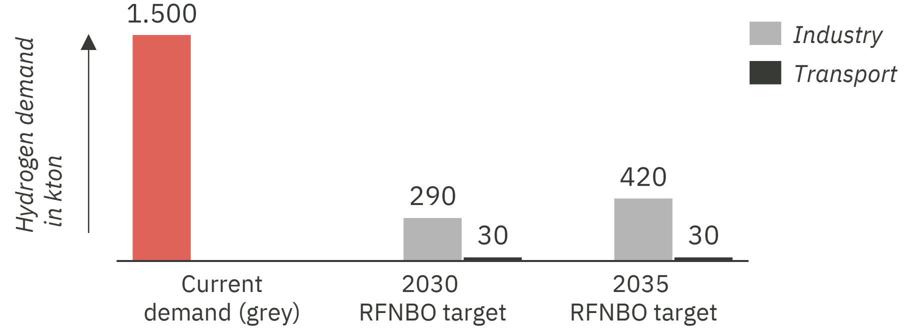
2050 Green hydrogen demand in the Netherlands

Projected demand for 2050 strongly varies based on the scenario. Ministry of Economic Affairs foresees rising demand up to 5.83 Mton (700 PJ) in the NPE, mainly driven by industry, e-fuels and power generation.[10] This would require an extreme local electrolysis capacity of around ~70 GW. Thus, this scenario considers up to 50% supply through import.

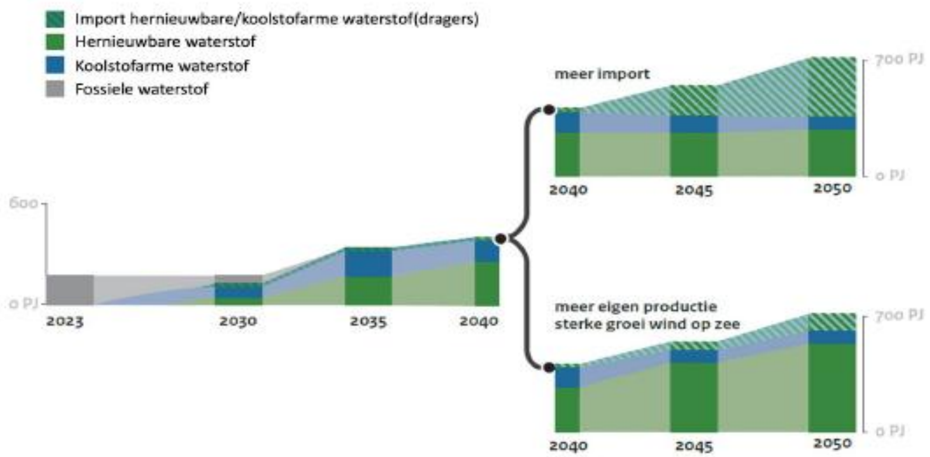
Import capacity in Dutch harbours will also be determined by the needs of neighbouring countries

The German hydrogen strategy expects 1.35-2.7 Mton in hydrogen demand to be met by imports in 2030 and the share of imports to increase in the years after.[11] The Belgian hydrogen strategy projects 90-180kton in demand for imported hydrogen (derivatives) in 2030.[12]

RFNBO targets for the Netherlands



Development of hydrogen demand and supply towards 2050 according to NPE



10: Ministry of Economic Affairs (2023) 11. BMWK (2023) 12. FSP Economy (2022)
** Based on 56 kwh/kg total electricity consumption and 4,800 FLH ** Invest-NL analysis*

Access to cost-effective hydrogen/green molecules

Lower hydrogen production cost in countries with favourable conditions for renewables show opportunities to drive the import of cost-effective hydrogen

Transport cost for all hydrogen carriers sit within the range of the cost gap between domestic hydrogen production and production in potential exporting countries

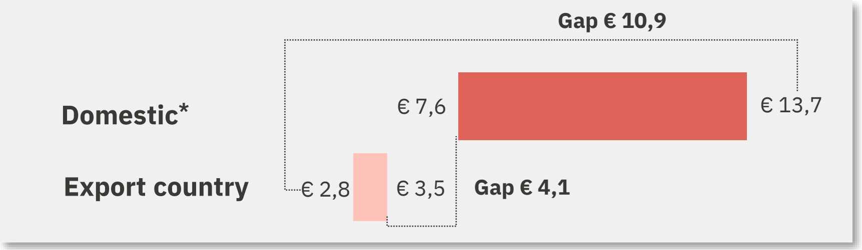
- TNO reveals a LCOH of €13.7/kg for projects currently under development in the Netherlands indicating a lower competitiveness than initially expected.[13] The recent European Hydrogen Bank auction shows that €7.6/kg was the lowest LCOH realized by a project in the Netherlands.[14]
- Based on confidential discussions between PoA and hydrogen exporting countries LCOHs in the range €2.8/kg - €3.5/kg are expected. This implies a production cost gap in the range of €4.1/kg – €10.9/kg. Note that the production cost for exporting countries disclosed in the latest discussions seems to be lower than the publicly available figures from PBL and TNO, indicating a range of €4.4/kg - €5/kg.[15]
- Meanwhile estimated transport cost for LH2, LOHC, and ammonia span a range of €1.5/kg - €5.5/kg based on research.[16, 17] The higher end of the ranges in table 2 corresponds to transport over larger distances and in smaller volumes. Based on these figures there seems to be a case for import irrespective of the chosen carrier.

Import of derivates such as ammonia, methanol, and e-fuels for direct use is most cost effective

- LH2, LOHC and cracked ammonia are particularly interesting carriers for applications where hydrogen is the final molecule. As is the case when converted to steel, heat or electricity, or in case of (bio)refining. The technology readiness levels (TRLs) of these carriers differ, and all contain steps where technological development and scale up is required.

13. TNO (2024) 14. European Commission (2024b) 15.PBL (2024) 16. TNO (2022) 17. Agora Energiewende & Industry, TUHH (2024)

Hydrogen production cost in Netherlands €/kg *(Compared to average cost in Oman, Egypt, Norway, Canada, Brazil, Spain, UAE and Saudi Arabia)*



production cost gap in the range of €4.1/kg – €10.9/kg

*2024 data with assumption operational in 2027

Hydrogen transportation cost to the Netherlands in €/kg. Including conversion cost.

	Agora Energiewende*	TNO**	TRL***
LH2	2.5	2.5 - 4.5	Liquefaction : 9 LH2 tanker: 7
LOHC	3.5 -5.5	2 - 2.5	Molecule: 5-7 Tanker: 11
Ammonia (cracked)	3 - 3.5	1.5 - 2.5	Cracking 6-9
Ammonia (direct use)	1.3	1 - 2	11
Methanol (direct use)	2	-	11
E-Fuels (syn-kerosene)	2.2	-	11

* 10500 km transport ** range for Argentina, Morocco, Australia, Oman, Iceland, United Kingdom, and Saudi Arabia. *** based on IEA ETP Clean Energy Technology Guide and Fluor [18, 19]; TRL 4-6: prototype; 7-8: demonstration; 9: commercial operation, 11 predictable growth

Applicability of existing subsidies (1/2)

There are subsidies available, with many of them only being focused on production. Incentives for hydrogen import have a limited budget and tenor, preventing financial commitment to projects.

	What is it?	Why (not) applicable?
VEKI	• CO_2 Limiting measures with a payback period > 5 years. • €130 m available till January 2025, focus on industry • Proven technology applies for capex investment	• Focus on proven technologies and local production
DEI+	• Pilot and demonstration projects • Green H_2: production, storage, transport and end-users • € 40 m fund size, > 80% available	• Usable for proving import-related technologies, not for financing the value chain
SDE++	• SDE = Stimuleren Duurzame Energie productie en klimaat transitie • Subsidy during operations calculated based on realized CO_2 reduction • Auction process for low carbon technologies with subsections for renewable molecules, low and high temperature heat • €1 bn budget for renewable molecules section	• Success rate for green H_2 is deemed low • Focused on local production, not import • Partly applicable when combined with CO_2 liquefaction process at import terminal
IPCEI	• Aimed at different green H_2 projects: import & storage, production, technology and mobility • All rounds are closed for applications. Import & storage budget was €600 m	• Deadline has passed • Limited funds
OWE	• Opschaling volledig hernieuwbare waterstofproductie via elektrolyse. • Combination of Capex (max. 80%) and Opex (max. 10 yrs) for eletrolysis projects 0.5 MW > • ~ € 1 bn budget	• Focused on domestic hydrogen production

Partly applicable **Not applicable**

Applicability existing subsidies (2/2)

There are subsidies available, with many of them only being focused on production. Incentives for hydrogen import have a limited budget and tenor, preventing financial commitment to projects.

	What is it?	Why (not) applicable?
European H2 Bank	• Production subsidy for green hydrogen • First round € 800 mn, subsidy € 0.5 per kg and production costs € 6 per kg • Only interesting if import of green H2 from EU partner (for example Bilbao) materializes	• Not applicable for import from outside EU • Import cases from within EU unlikely to bid competitively
H2 Global	• 2-sided auction with CfD approach to close cost gap between sales and purchase price • LT purchase contracts (10y) on supply side, ST sales contracts (1y) on demand side • Over €5 bn committed, Netherlands committed €300 mn	• Limited Dutch funds • Tenor mismatch, too short
Innovation fund	• Decarbonize European industry • Also focus on green hydrogen • € 40 bn till 2030, EU wide; € 1.7 bn available for large projects with capex above €100 mn in 2023	• Highly competitive; 15 projects will be financed • Import not main focus
CEF Energy	• Aimed at building Trans-European energy infrastructure • € 5.84 bn available for 2021-2027 • € 850 m available for current call, 50% cofinancing of project • Project duration until end of 2030 with possible extension	• Potentially feasible as import terminal are covered but required to get on PCI list and apply for TYNDP membership first. Outcome dependent on political support • Limited fund size and limited tenor

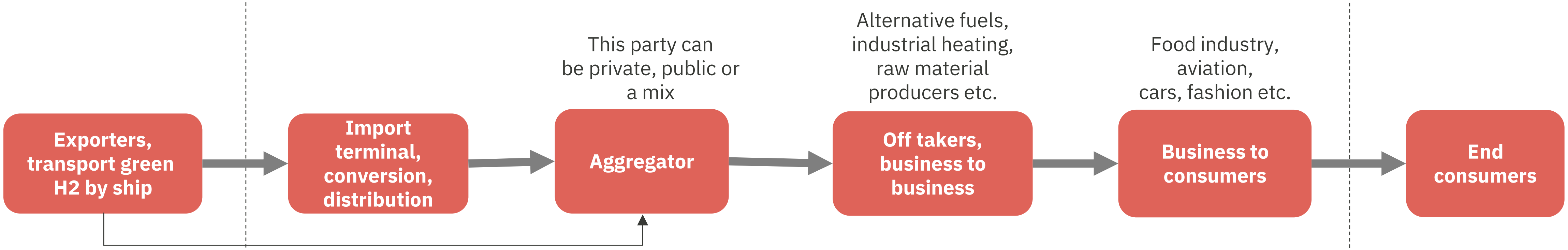
The currently available governmental instruments are mostly focused on local production (within the Netherlands), are insufficient to cover the financial gap (too small, too competitive), and applied to individual projects and companies (instead of a varied offtake profile). For green hydrogen import cases with a varied offtake profile to find proper financing, additional governmental intervention is desired.

Partly applicable (yellow) | **Not applicable** (pink)

Section 3: The Value Chain for Import of Green Hydrogen

High level overview of the value chain for the import of green H2

Focus of the analysis is on the business case for liquid green hydrogen at the Port of Amsterdam



Exporters, transport green H2 by ship

Description

- Great variety of locations for possible green hydrogen production determining the attractiveness in price
- Transportation costs differ per carrier/method
- Market readiness and ease of integration into current process differs per carrier/method

Import terminal, conversion, distribution

Description

- Ease of storage and integration in terminal dependent on carrier/method
- Additional requirements for safety purposes likely
- Additional capex required to deliver H2
    - Reconversion
    - Storage
    - Grid connection
    - Pipelines

Aggregator

Description

- This party act as an intermediary for exporters and off-takers of green hydrogen within different sectors and regions, enabling one point of contact
- The aggregators can combine demand of smaller off-takers in a larger total volume which can enable the required minimum offtake for a viable business case
- The aggregator can service off-takers with different willingness to pay and as such realize the highest willingness to pay

Off takers, business to business

Description

- B2Bs looking into replacing Fossil Fuels for Green H2
- B2B refining new fuels using H2 as feedstock > transportation, industry.

Business to consumers

Description

- B2C which need and want to decarbonize their products
- B2C which are required by law to decarbonize

End consumers

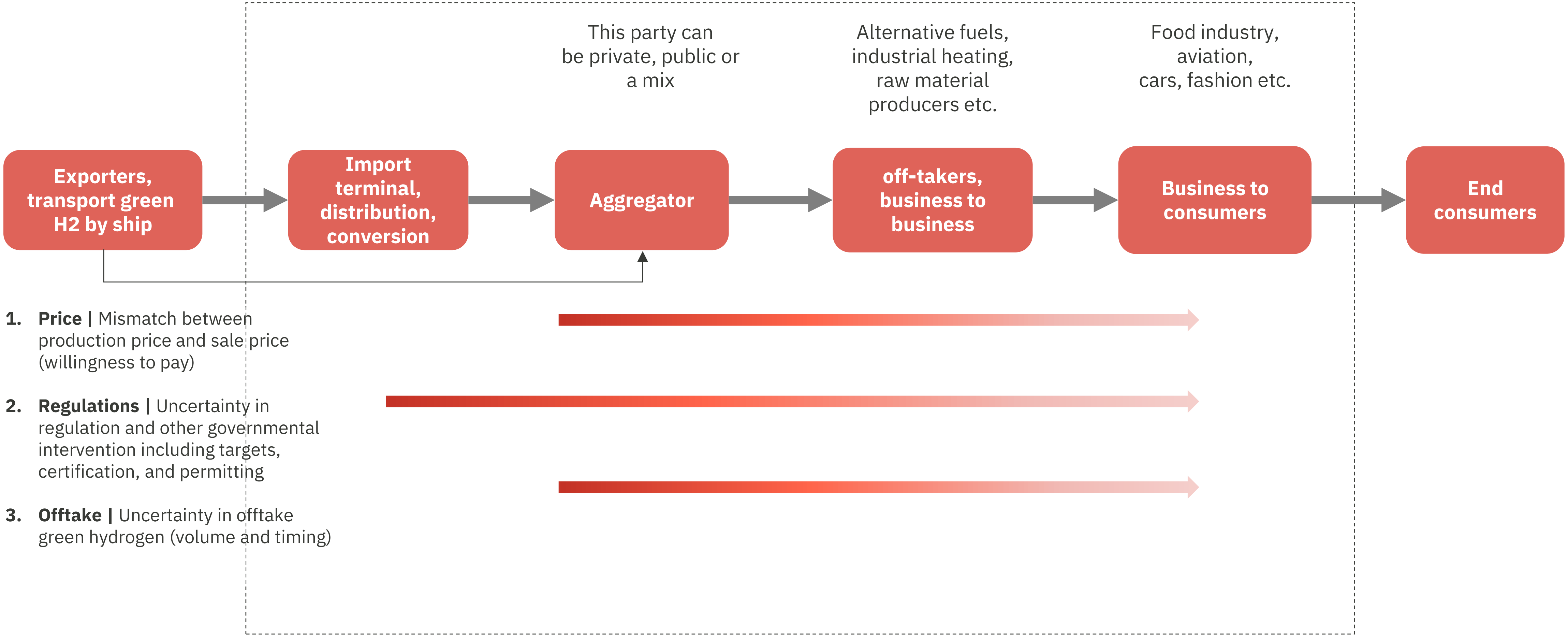
Description

- Consumers willing to pay more for greener products

---- **= focus of the analysis**

Key risks within the value chain of green hydrogen

The major risk are a mismatch in production cost versus willingness to pay, uncertainty in offtake volume and uncertain regulation



1. **Price |** Mismatch between production price and sale price (willingness to pay)
2. **Regulations |** Uncertainty in regulation and other governmental intervention including targets, certification, and permitting
3. **Offtake |** Uncertainty in offtake green hydrogen (volume and timing)

---- **= focus of the analysis**

Section 4: Potential offtake for the Port of Amsterdam

Transition to a European hydrogen hub

The Port of Amsterdam is well-positioned for potential green hydrogen import due to its attractive position for both local offtake and throughput

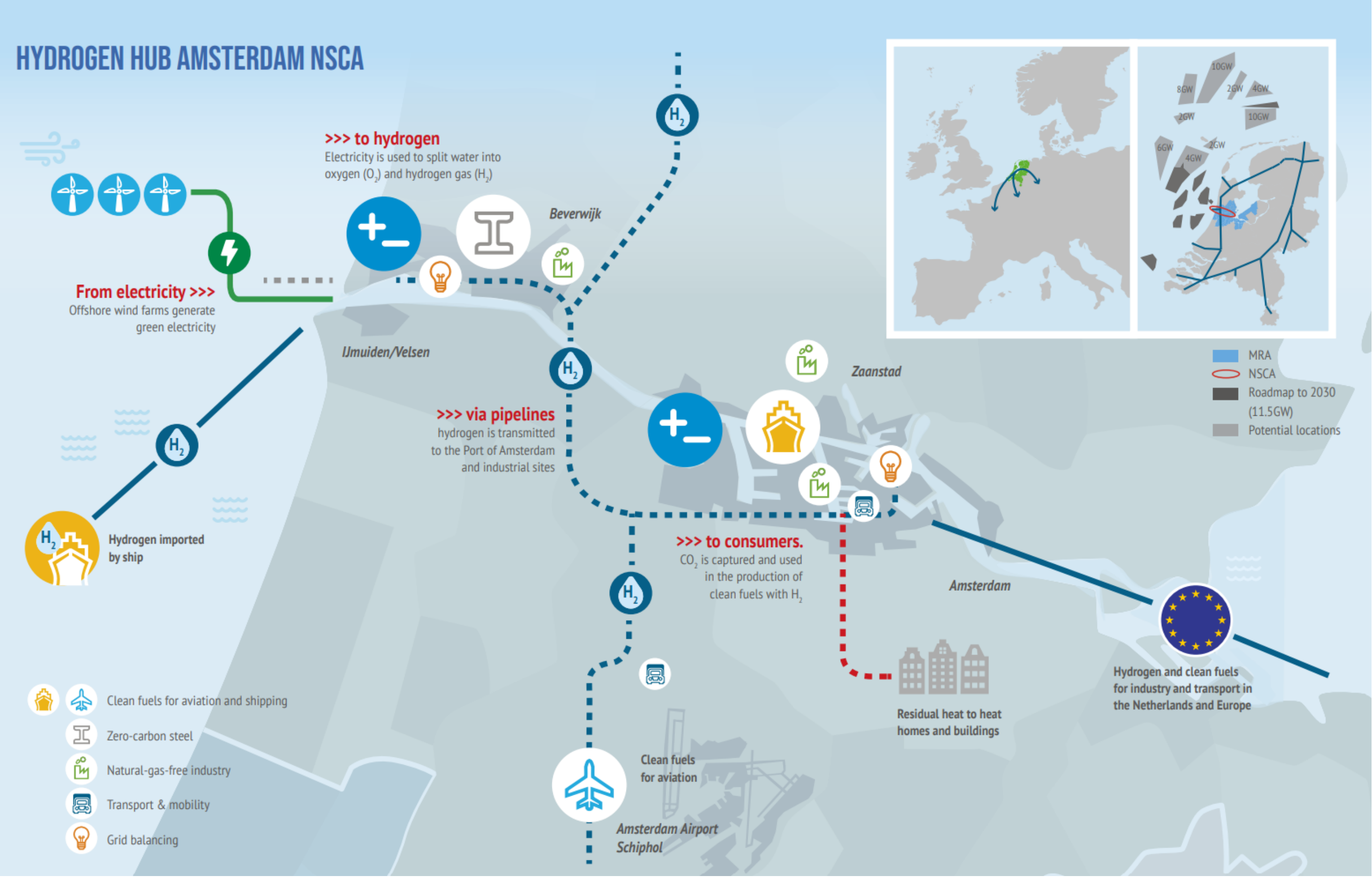


Image from NSCA[20]

Amsterdam can be considered as a **hydrogen hub** for the import of hydrogen due to the following characteristics:

- Port of Amsterdam has an attractive position to import green hydrogen considering its location and PoA's relevant experience in importing goods that are subsequently transferred to other regions.
- Both local offtake for green hydrogen and throughput to other regions including Germany could be facilitated through the port of Amsterdam.
- The demand for green hydrogen in the area is mostly based on industries that are currently not using (grey) hydrogen. Some industries therefore will require (significant) investments.

Liquid hydrogen is a carrier of choice for PoA

Liquid hydrogen is worth exploring further as route for import into the port of Amsterdam

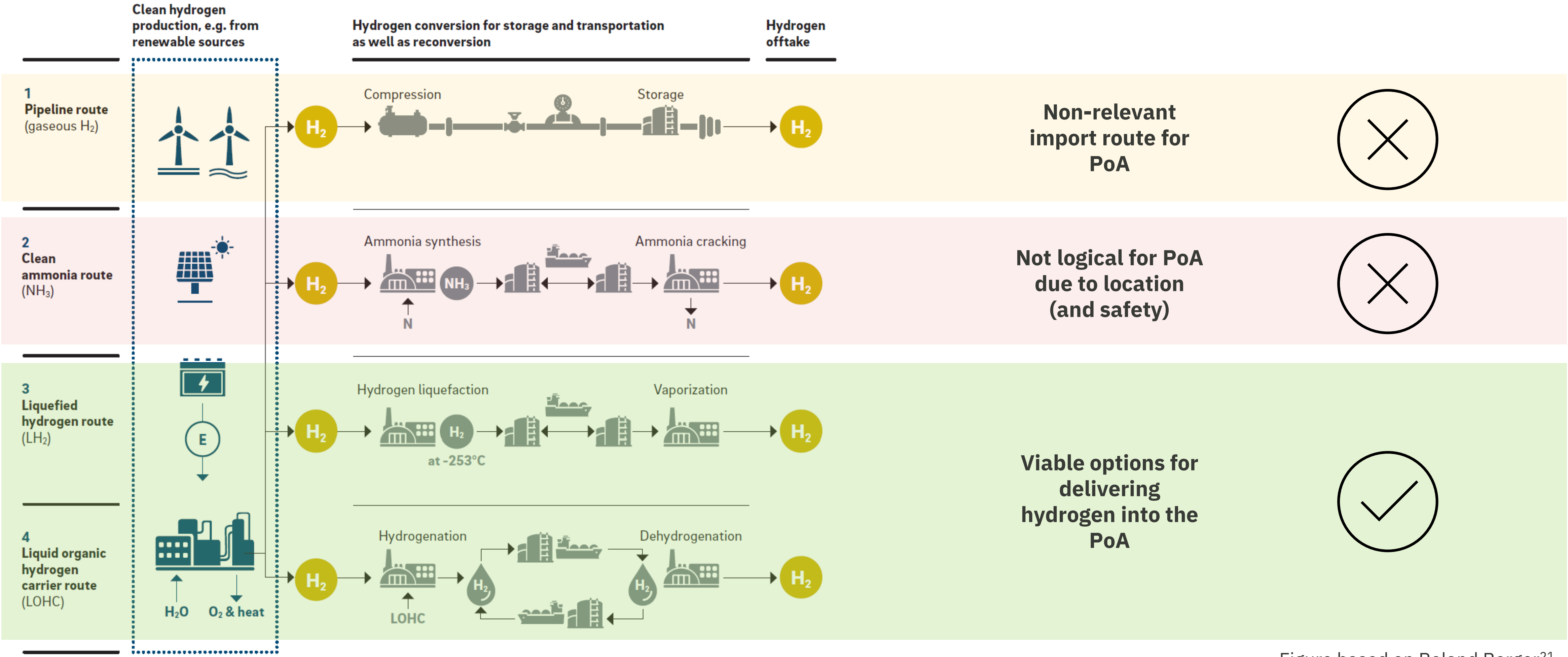


Figure based on Roland Berger[21]

Market consultation analysis

Interviews with a potential aggregator, numerous potential off-takers, network operators and terminal operator form the basis of our analysis

Scope of work

- The market consultation was comprised of interviews with the consortium (Port of Amsterdam, ECOLOG and Tata Steel), interviews with 8 potential off-takers in or near the NSCA, network operators and a potential aggregator.
- In addition, via desktop research and references from the interviews a wide range of studies were consulted.

Limitations

- The impact from governmental regulations and incentives (for instance state level implementation of RED III) can be hard to quantify.
- The data used to estimate potential offtake volumes is not comprehensive and needs further analysis.
- Price estimations are based on assumptions on upcoming regulation, market movements, price differentiation etc. These are to be verified further.
- Public studies varied in geographical focus and system boundaries which impairs consistent comparison.
- The costs and practical considerations of green hydrogen transportation through pipelines over long distance are not included.
- This study only covers liquid hydrogen as carrier solution.

Relevant sectors PoA

- The use of green hydrogen is of interest for various sectors.
- For this study focusing on liquid hydrogen and import through the Port of Amsterdam, we have reduced the scope of sectors reviewed for this report.
- These sectors are; steel, aviation, shipping, heavy duty vehicles, and other industries (food & beverage, plastics, glass and cement).
- The Port of Amsterdam can ensure the supply of green hydrogen in the NSCA, rest of the Netherlands and Germany. The latter depends on the readiness of pipelines among others (HyNetwork).

Aggregator

- The business case assumes the role of an aggregator. They are key to ensure a balanced offtake profile and secure contracts.
- The aggregator signs off take contract with a large number of (smaller) off-takers and bundles demand. Simultaneously the aggregator signs an offtake contract for a longer period of time with the terminal operator.
- This long-term contract provides the necessary certainty with respect to offtake typically required by financing parties. It also provides comfort for the terminal operator.

Other interviews

- The interviews with potential off-takers supported in most cases the views of the aggregator regarding willingness to pay.
- They provided us with a solid overview of the market requirements and applicable regulations.
- Depending on the off-taker, more detailed information about future demand and price points were provided, as well as overall market potential.

Potential sectors for the offtake of green hydrogen through the port of Amsterdam

The projected prices and volumes for each sector highly depend on upcoming regulatory and other governmental incentives

	Aviation	Short sea shipping	Heavy Duty Vehicles	Steel	Other industries
Description and regulations*	*Synthetic fuels are key for decarbonizing aviation . Uptake is driven by ReFuelEU aiming for a 1.2% share of synthetic fuels in 2030*	*Hydrogen is a promising solution for decarbonization of short sea shipping. Decarbonization is driven by FuelEU maritime legislation, but up to 2034 no specific RFNBO target is expected*	*Hydrogen is expected to contribute to an emission free heavy duty vehicles sector. RED III and the specific RFNBO targets for the transportation sector are fundamental for the uptake*	*Hydrogen (blending) in a DRI process will be an essential pathway for decarbonized steel. No regulations in place yet that specifically promote the uptake of hydrogen apart from the EU ETS*	*Due to low incentives currently for the paper, glass, cement, f&b sector the industry relies on own motivation and initiatives to move towards green hydrogen*
Estimated potential throughput in 2030	80 kton in 2030, regulations could result in a larger potential in the years after	5 kton in 2030, limited growth expected in years after	25 kton in 2030, further uptake depending on FCEV initiatives from automotive industry	50 kton in 2030, potentially largest offtake in NSCA area (300kton)	70 kton in 2030, with larger volumes expected in the years after
Pricing estimates 2030	Possibly € 14 per kg with low availability of eSAF, reaching an expected equilibrium at € 4-7 per kg	Probably competitive if the price is between € 6-7 per kg	Capped by battery technology and an estimated price of € 4 to 5 per kg	An estimated price for niche steel markets between € 4 and 7 per kg	An estimated price of € 6.5 per kg
Viability	Regulatory incentive to use green hydrogen; implementation dependent on investments being made within the next years	Though the incentive through regulation is limited, the first hydrogen ships have been ordered	Hydrogen competes heavily with biofuels and battery solutions, but is expected to be adopted for a fraction of the heavy-duty segment	Strong dependency on governmental initiatives and-or market willingness for green products	Strong dependency on own initiatives, demand for green products and future regulations

*Details of the markets are displayed on the following pages

Demand projections (delivered through the port of Amsterdam)

Market consultation provides a first indication of offtake potential and willingness to pay for hydrogen delivered

Potential demand curve for import through the port of Amsterdam in 2030

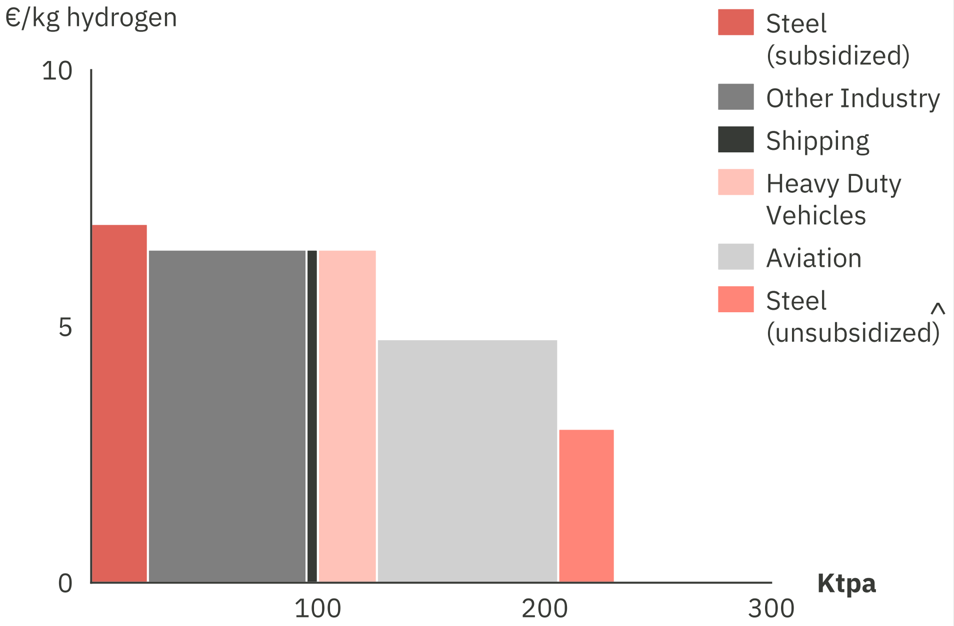
The projected demand covers demand from within the NSCA region, the rest of the Netherlands and Germany that can be met by imports through the port[1]. The presented demand curve is particularly focused on the sectors present in the NSCA region, which have been interviewed within the scope of this study. Hence, the offtake from chemical industries and refineries has been omitted.

- A 230 kton demand curve with a **willingness to pay (WtP) generally ranging from €3/kg to €7/kg hydrogen at the customer site** can be established. In the business case calculations, a weighted average WtP of €5.5/kg has been applied.* The exact WtP at the port is expected to be lower than indicated average and depends on transportation and/or distribution cost to the off-taker.
- In reality, an off-taker will agree on a price with the aggregator, which will be determined by its sector. **The aggregator will subsequently determine the hydrogen price for the import contract based on the different underlying offtake agreements**.
- Other sectors such as refining could benefit from liquid hydrogen imports. WtP for these has been estimated to be respectively €6-9/kg hydrogen Germany. [22] Although these sectors have not been included in the analysis and the business case, it suggests that higher offtake prices could be secured given that the necessary infrastructure is in place. The additional transportation cost will need to be considered in that perspective.

Nearly 75% of demand located outside of the NSCA region

In 2030 80 kton is expected to be consumed within the NSCA region and at least 150kton outside the region. The expected volumes outside the region are an estimate of the market that could be served through the NSCA region with a liquid hydrogen import solution. Hence these volumes do not reflect a total market size for green hydrogen in the Netherlands and neighbouring countries.

Green hydrogen off-takers' willingness to pay in 2030



^ Based on production costs with natural gas and projected national CO2 tax in 2030

22. BCG (2023); Based on strategic behaviour willingness to pay may actually be lower or higher*

Market dynamics | Aviation

Market potential for eSAF is large and incentivized by regulation, but uncertainty remains around the competitiveness eSAF production facilities in the region

Regulations and incentives

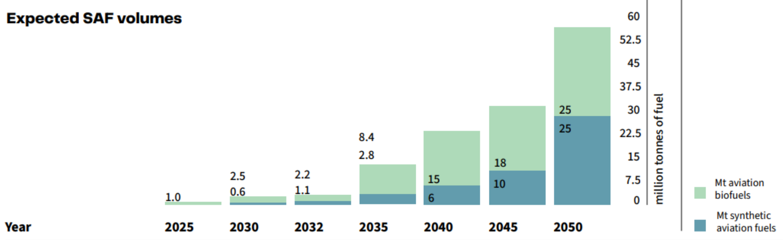
With the adoption of the **ReFuelEU Aviation** regulation, the EC installed mandatory blending quotas for sustainable aviation fuels (SAF). Within the different types of SAF, Synthetic Aviation Fuels (**eSAF**) will drive the demand for green hydrogen as it covers a.o. Kerosene produced with renewable hydrogen (RFNBOs,) and a renewable carbon source (biogenic or atmospheric). Every kton of eSAF requires 0.5 kton of green hydrogen and 4kton CO2.

The table below shows the binding SAF targets included in the ReFuelEU Aviation regulation. The proposed rules set a sub-target (dark-green) to ensure that a certain amount of SAF will consist out of synthetic fuels. Not meeting the targets will trigger a **penalty** for the relevant party (fuel supplier, EU airport or aircraft operator).

EU-wide quotas

Year	2025	2030	2032	2035	2040	2045	2050
Share of SAF	2%	6%	6%	20%	34%	42%	70%
Minimum share of synthetic aviation fuels	0%	1.2%*	2%*	5%	10%	15%	35%

* Average share of 1.2% for the period 2030 - 2031 and average share of 2% for the period 2032-2034



Source: Eurostat Database (2024); growth assumption aviation market 1.5% per annum (according to the International Civil Aviation Organization, ICAO, medium scenario)

Updated: May 2024

Table 1 – SAF Targets[23]

Throughput the port of Amsterdam

The expected demand forecast from ICAO for European demand for e-fuel amounts to 300 kton in 2030, increasing to 1200 kton in 2035. Based on market consultation a total throughput for the port of **80kton in 2030** is expected.

Prices and tenor

As a result of the new eSAF regulations*, the market demand is expected to increase. In a maximum scenario € 14/kg may be achievable as this amount equals the penalty for not following the eSAF regulations in case of limited availability of sufficient eSAF fuel. More realistically, certainly in the short to mid term, is a price range **in-between € 4 and € 7 per kg** with an average price of **€ 5 per kg**.

Viability

There are currently a few hurdles for local eSAF: (1) The **eSAF production facility may be better located in a country with a comparative advantage** in cheap 24/7 renewable electricity. (2) Currently there is limited biogenic CO2 available in the Netherlands, as capture and commercialization of biogenic CO2 is still under development. (**3**) Shipping eSAF is cheap and easy via existing infrastructure (comparable to kerosene). (4) If the “book and claim" method is adopted, aviation companies can trade **eSAF credits** with each other and local production in Western Europe of eSAF may not be necessary.

Due to the expected total demand for the aviation sector, requirement to provide SAF by EU airports (EU Airports with passenger traffic above 800,000 passengers or freight traffic above 100,000 tons per year must make the refueling of SAF possible) and Amsterdam’s strategic location, it is reasonable to assume green hydrogen throughputs through the port.

*23. Now-GMBH (2024) * 1) Minimum fines for Aviation Fuel Suppliers: 2 x [Difference SAF or synthetic aviation fuel price - conventional kerosene price per tonne] x quantity of aviation fuel not complying with the quota 2) EU Airports: Fines shall be defined and structured by Member States; 3) Minimum fines for Aircraft Operators:, 2 x yearly average price of aviation fuel per tonne x yearly non-tanked quantity*

Market dynamics | (Short sea) shipping

Though the incentive through regulation is limited, the first hydrogen ships have been ordered

Regulations and incentives

There is demand for subsidies from the EU Innovation Fund for ships on hydrogen. Currently a 50% capex subsidy is required for the hydrogen installation, to have a viable business case.
If you take a deep-dive at granted subsidies by ENOVA (Norway) and the Netherlands' Maritime Masterplan, a dozen ships on hydrogen is expected to be delivered in 2027-2028. Thereafter, the market expects an increased demand in hydrogen propelled ships, provided positive feedback of the first movers on the technical challenges and more insight in viable business cases.

Regulations like: EU-ETS, fuel EU Maritime, IMO's CII and EEDI index, are **significant drivers** for the future uptake of green fuels within the fleet. However, it can be questioned if their current impact is too low and whether these rules **need to be more ambitious** to encourage green fuel uptake. The FuelEU maritime requirement of 2% non-fossil fuels in 2025 can easily be met with some biofuels. The impact starts to be more significant from 2030 onwards, when 6% is required. If the share of RFNBOs remains less than 1% of all fuel usage within scope of the regulation by 2031, then **a sub target will mandate 2% RFNBOs from January 2034 onwards**. In favor of green hydrogen, the usage of RFNBO counts double in the adherence to the upcoming regulations.

Throughput the port of Amsterdam

Market consultation indicated that liquid hydrogen could be a favorable choice for **short sea shipping segment**, simply because green ammonia and green methanol will be more expensive to produce, and batteries will not have enough range. The estimated throughput is **5 kton in 2030**.

Prices and tenor

The requested longer duration of offtake contracts may cause some difficulties with the suppliers of green fuel. Because fleet owners want to avoid **very long-term contracts** where fuel costs could become too high in comparison to the competition and because lower prices are to be expected by interviewees due to more and better technologies implemented in producing Hydrogen.
The market players consulted foresees a price range between **€ 6 to 7 per kg** and indicate that "liquid hydrogen is cheaper than methanol and safer than ammonia and should be the **most competitive green alternative for the purpose of short sea shipping**".

Viability

Shipping companies within the NSCA region have ordered hydrogen fueled vessels, yet **the lack of green hydrogen supply** may slow further uptake of hydrogen fueled vessels. Short sea shipping companies within this market consultation have indicated that in terms of economics hydrogen fueled ships can be competitive with diesel fueled ships.

Market dynamics | Heavy duty vehicles (HDV)

REDIII incentivizes offtake of green hydrogen for transportation and is expected to be most competitive within the heavy-duty market segment

Regulations and incentives

From 2030 onwards (RED III, art. 25), a minimum of effectively 0.5% or 33 kton, of all transportation fuels need to be RFNBO within the Netherlands.[24] RFNBO's credits can also be gained via usage of green hydrogen in the refinery process, replacing the additional steam reformed (SMR) produced grey hydrogen. The potential is estimated to be 130 - 280 kton.[25] Given ~50% of the refinery's products are used within NL, half of this range can count towards RFNBO targets. Within road transportation heavy duty vehicles (HDV) seem to be the only viable subsegment for direct hydrogen use.

Throughput the port of Amsterdam

It is estimated through market consultation that the total throughput in the port of Amsterdam will amount to ~**25 kton of green hydrogen in 2030.** For 25 kton hydrogen demand ~4,000 FCEV trucks driving ~ 75,000 km per year need to be operational.[26]

A coalition of big vehicle manufacturers including Daimler, Honda and Hyundai is committed to deploy 100,000 fuel cell trucks by 2030 to support the "decarbonisation of the European transport sector. Of total new truck sales 17% of new trucks in 2030 are expected to be running on hydrogen. This would translate into almost 60,000 trucks, according to the study.[27]

Prices and tenor

As from 2030 onwards, the market is expected to be somewhere in between € 3 and € 6 per kg. To transport and pump it into the FCE truck another € 2 needs to be added for the intermediate steps. To be on TCO parity within the Netherlands, with their diesel counterparts, the breakeven price (2030) at the pump is calculated to be €5 per kg **Market consultation resulted in an estimated average price of € 4.5/kg.**

Viability

A few hurdles for the sector are: 1) the ramp up of the RFNBO target post 2030 is unclear; 2) currently battery powered commercial vehicles are quickly becoming the standard option for light duty commercial vehicles, but also for medium and heavy-duty segments; Only FCEV accounted for only 5% of zero emission medium and heavy-duty trucks sold in the first half of 2024.[28] FCEV sales are strongly concentrated in China. FCEV trucks seem a big(ger) leap given higher TCOs and vehicle prices compared to BEV trucks, and other unknowns such as limited fuelling stations. Also, the role of FCEV medium and heavy trucks seems to be decreasing in net zero scenario. BNEF estimates a 10% FCEV fleet share in 2050.[29]

The estimated volume, however, is a relative low percentage of the total road transportation market (378.4PJ within NL) and is therefore considered to be reasonable.

1 liter of diesel is equal to 10 kWh. An average road truck, consumes 30 liters of diesel per 100 km[26], which is equal to ~ 350 kWh. 1 kg of hydrogen processed by a fuel cell with 50% efficiency produces 17kWh. To drive 100 Km electrical ca. 140 kWh is required, hence, 8.5kg hydrogen is sufficient. If you burn 30 liter of diesel, you produce 75kg of CO2[30]. Today 1 liter of diesel to road trucks costs excl. vat: €1.55 and the ETS for CO2 is €65 per ton[31]. Hence if you compare than diesel + CO2 with green hydrogen, you would be better off paying less than €6 per kg for green Hydrogen at the pump.

24. TNO (2022) 25. TNO (2024a) 26. ICCT (2023) 27. Euactiv (2021) 28. BNEF (2024) 29. BNEF (2024b) 30. Co2emissiefactoren (2024) 31. TLM (2024)

Market dynamics | Steel

The Dutch and German steel sector are both looking into the potential of green hydrogen with its viability highly reliant on the government incentives (to be) provided

Regulations and incentives

There are no strict regulations such as RED III that create the need for green hydrogen for the steel sector. Both the Dutch and German government are therefore looking into incentivization of green steel. The German government has taken several billion-euro measures to support German steelmakers, which have been approved by the European Commission. [32, 33, 34]

The Dutch Government and Tata Steel are in discussions on pathways to reduce the CO2 footprint of Tata Steel. **The objective is to have a Direct Reduced Iron (DRI) plant operational by 2030,** with another DRI planned to replace the second (and final) blast furnace a few years later. An option for further CO2 reduction would be the use of CC(U)S.

Throughput the port of Amsterdam

It is estimated through market consultation that the total throughput for the port of Amsterdam will amount to **50ktonnes** of green hydrogen in 2030.

The largest potential demand for green hydrogen in the NSCA area can come from the steel industry. Within the Netherlands the demand could be 120kton in 2030, up to potentially ~300kton in 2037 (depending on the percentage hydrogen mixed in). The market demand for green hydrogen from steel producers in Germany is potentially a multitude compared to the potential market demand within the Netherlands with potential future demand estimated at 850 kton by 2030.[35]

Prices and tenor

The **steel market is global and known to be very competitive.** Current market characteristics **dictate price following**, reflected in a low willingness to pay for green hydrogen in general.

Some German steel manufacturers will allocate a portion of their production capacity for green steel products and are possibly prepared **to pay up to € 7 per kg** for green hydrogen. This is **stimulated by German subsidies** and green demand from automakers for example. The Dutch incentives to start using green hydrogen are still to be determined in the Netherlands according to our market consultation. This currently results in a lower price acceptance with an estimated max price level of **~€3 per kg**.

Viability

The **hydrogen demand is driven by initiatives of the National governments** whereby the Dutch government stimulates the realization of DRI's with the possibility for additionally required measures in the future and the German government providing subsidies to stimulate the use of green hydrogen by steel producers. Automakers and other **clients willing to pay a premium for green steel could accelerate uptake** of hydrogen in the steel sector.

32. European Commission (2023) 33. European Commission (2023a) 34. European Commission (2024c). 35 EUROMETAL (2024)

Market dynamics | Other industries *(food & beverage, paper, cement, glass)*

With regulations for the industry still falling behind, the sector demand depends on own initiatives and ambitious goals of industry players themselves

Regulations and incentives

Other industries covers sectors where hydrogen could provide an alternatives to natural gas to generate mid and high temperature heat. There are no specific regulations such as RED III that create the need for green hydrogen in sectors that are currently not using hydrogen. EU ETS is the dominant driver of decarbonization. Nevertheless, many industrial companies have set CO2 reduction targets. For instance, the **food and beverage** companies may start using green hydrogen as a **marketing tool** to service their environmental conscious clients.

Throughput the port of Amsterdam

The throughput for the other industries can amount up to **70 ktonnes in 2030** according to market consultation. There will probably be a **mix of users** whereby the **more energy intense companies** in the paper, glass and cement markets will consume **the bulk.** Food & beverage is estimated to create a smaller demand.

Prices and tenor

Off takers in food & beverage for whom it's a small part of their total cost price are according to market consultation willing to pay up to € 12 per kg. Paper, glass and cement companies are active in a more competitive market and the energy costs are also a larger part of their cost price. Therefore, these companies are probably prepared to pay a price of between **€ 5 to 8 per kg. Market consultation indicates an average price of € 6.5 per kg.**

Viability

The **cement industry** can be characterized as a hard-to-abate industry as they need high temperature heat and cannot switch to electrification. Hydrogen offers a solution for these companies to decarbonize. However, the application of hydrogen in the cement production process requires a major redesign of the burner which will likely delay the switch to hydrogen.[36]

From a volume perspective there is potential for hydrogen application in the **glass industry** as this industry produced 40 million tonnes of glass and emitted 22 million tonnes of CO2 in the EU.[37] The required high and constant temperatures in the production process cannot be achieved by electrification. Pilots show that blending hydrogen with natural gas can be the first step of the glass industry's decarbonisation efforts.

For the **paper industry** relatively small modifications are needed to replace natural gas with hydrogen in the production process. Several pilots have started. The main barrier for switching are the high-cost level of hydrogen and uncertainty around supply. However, as specific industry partners were not interviewed, a more in-depth analysis is required to further determine the viability.

Representatives from the food and beverage industry were not part of the selected interviews, but were among market players mentioned as a potential off-taker against a competitive price.

36. DNV (2023) 37. E.ON (2022)

Section 5: Business case

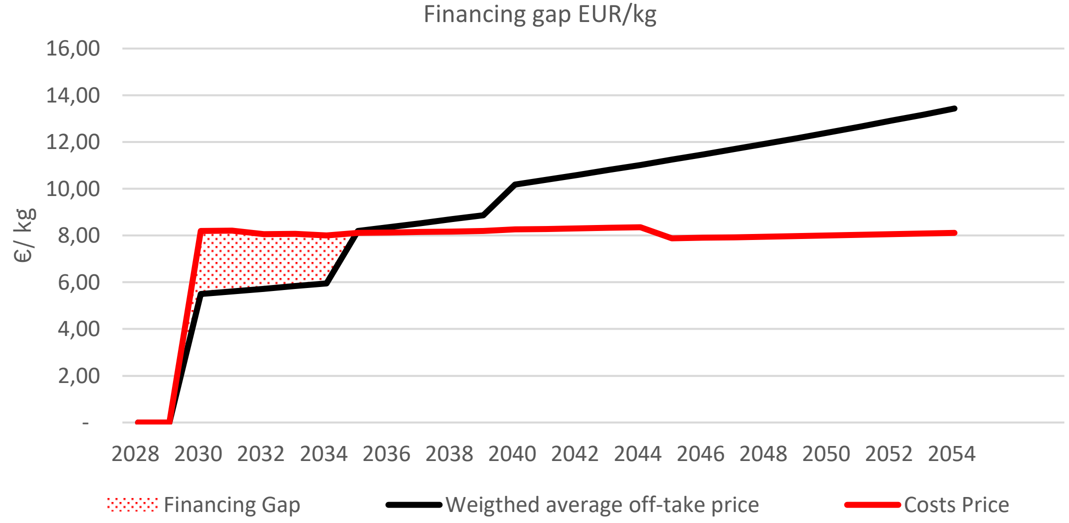
Base case - Financing gap

Depending on the cut-off period, the base case shows a positive or negative gap

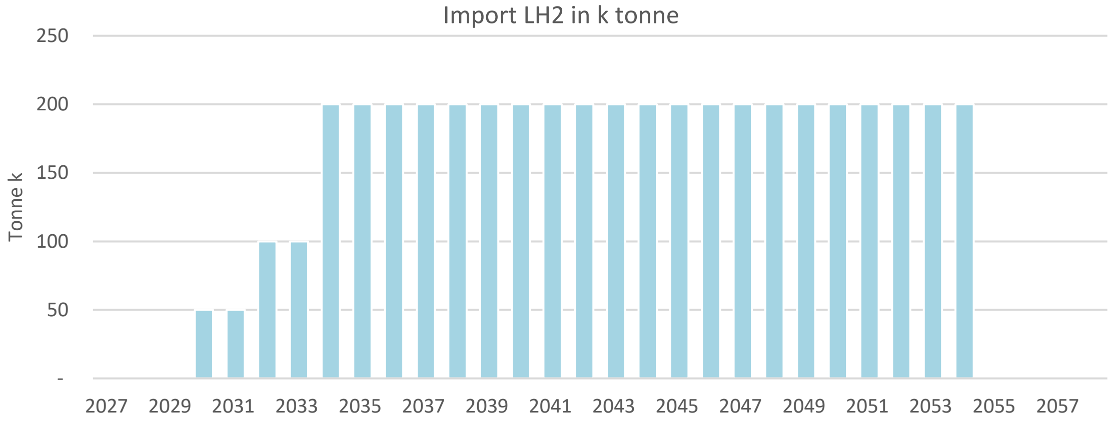
Import in the Port of Amsterdam

For the business case, the import of hydrogen through the Port of Amsterdam is expected to be 50k tonne of LH2 in 2030 and 2031, 100k tonne in 2032 and 2033 and 200k tonne from 2034 onwards due to the ramp-up of the terminal (see graph on the right). *

The cost price of hydrogen (below in red) is assumed to initially be higher than the weighted average off-take price (in black), leading to a “financing gap”. Due to differences in indexation assumptions – as well as changes in assumptions for real production costs and willingness-to-pay – the average off-take price overtakes production cost in 2040. Over the entire 25-year forecast period, the base case results in a net financing surplus of ~€2,400 mn.



200 ktpa max. is modelled, but the terminal capacity could be increased to 600ktpa eventually



Time period	Financing gap/(surplus)
2030 – 2039 (10Y)	€2,300 mn
2030 – 2044 (15Y)	€1,900 mn
2030 – 2049 (20Y)	€200 mn
2030 – 2055 (25Y)	€(2,400) mn

Assumptions overview: cost price

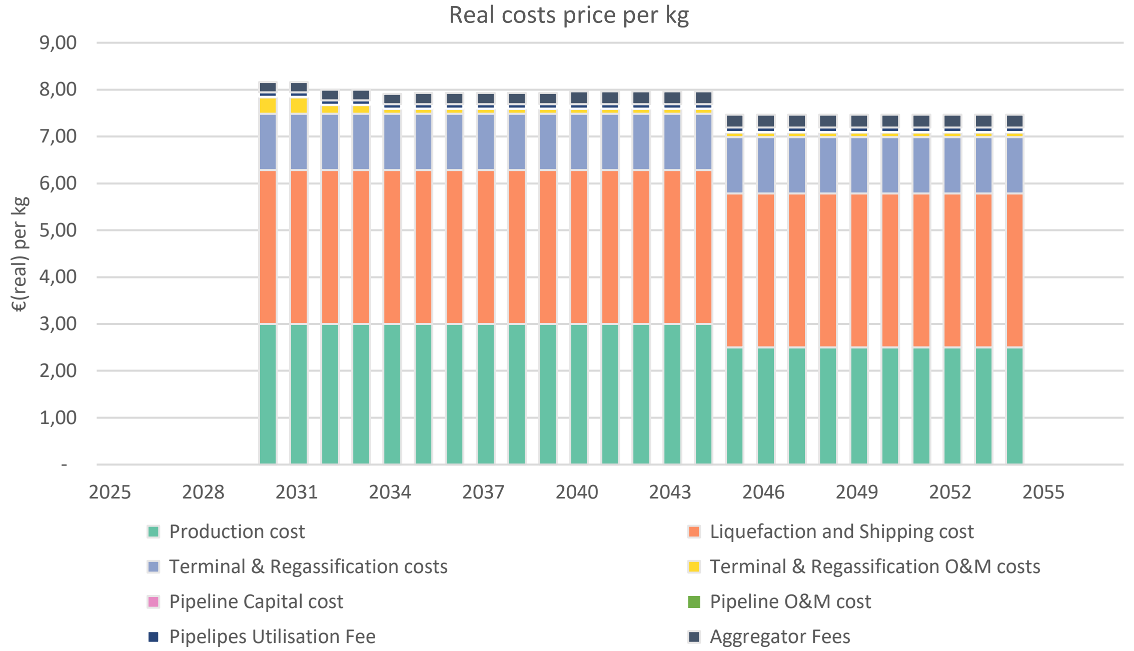
Green hydrogen cost price ready for offtake

Drivers of the costs price of LH2 in Amsterdam

While many factors contribute to the total costs price of LH2, the most important are the assumptions for production, liquefaction and shipping costs. The amounts below are shown in real and nominal prices. The project team has assumed a 17% decrease in production cost after year 15 (from €3.00 per kg to €2.50 per kg). The graph on the right shows the decrease of the costs price in 2045 as a result of that. The assumption regarding the production costs is lower than the shown costs scenarios on slide 17, which is based on discussions with all involved parties. As is also mentioned on the next slide, the base case is highly dependent on these assumptions and will fluctuate accordingly (see also slide 38).

The table below shows the prices in the first year of full operations (2034).

Cost Price (2034)	Amount (Real)	Amount (Nominal)
Production cost	€3.00 per kg	€3,00 per kg
Liquefaction and Shipping cost	€3.29 per kg	€3.34 per kg
Terminal Fee (incl. O&M)	€1.30 per kg	€1.31 per kg
Pipeline (Firan)	€0.009 per kg	€0.010 per kg
Pipeline (Hynetwork)	€0.095 per kg	€0.114 per kg
Aggregator	€0.22 per kg	€0.24 per kg
SUM cost price	€7.91 per kg	€8.01 per kg



Assumptions overview: hydrogen purchasing price

Weighted average hydrogen purchasing price through aggregator

Increasing willingness-to-pay in 2035 and 2040

The amounts below are shown in real (2030) and nominal (2034) prices. This price is based on several interviews with potential off-takers in the NSC-region, as well as the aggregator.

The project team has assumed a 10% increase in the “willingness-to-pay” in 2035 and a 12.5% increase in the willingness-to-pay in 2040, based on an expected increased demand for hydrogen in the coming years and, mostly, the effect of (the enforcement of) regulation regarding hydrogen in Europe and the Netherlands. This effect will be partly offset by an increased supply in those years, but the underlying assumption here is that that effect will be smaller than the increased demand.

Willingness-to-Pay	Amount (Real)	Amount (Nominal)	Source
Expected hydrogen market price	€5.50 per kg	€5.95 per kg	Interviews
Weighted average financing gap	€2.69 per kg	€2.05 per kg	Model result

The weighted average hydrogen price has been based on a limited amount of data and should be considered a reflection of the market consultation performed that requires further validation. The outcome is highly sensitive to the selected sectors, volumes and indicated price ranges per off-taker. In practice, the outcome could differ.

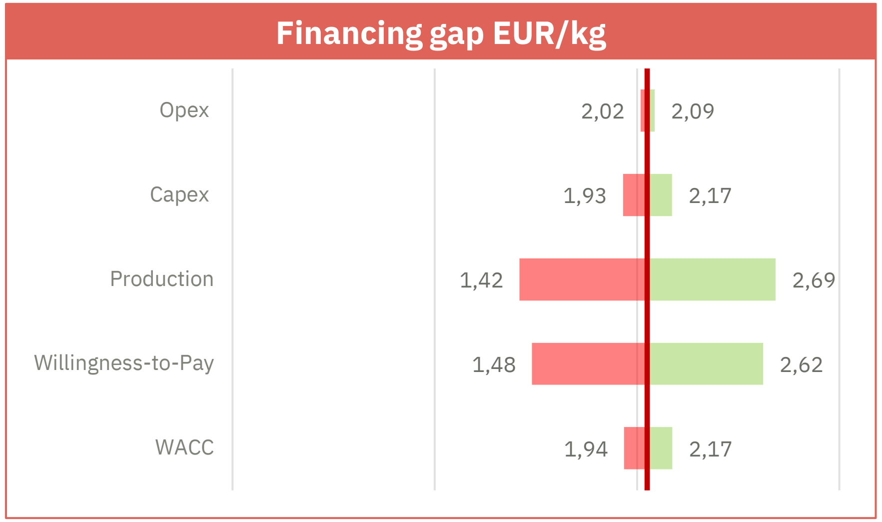
Sensitivity analysis

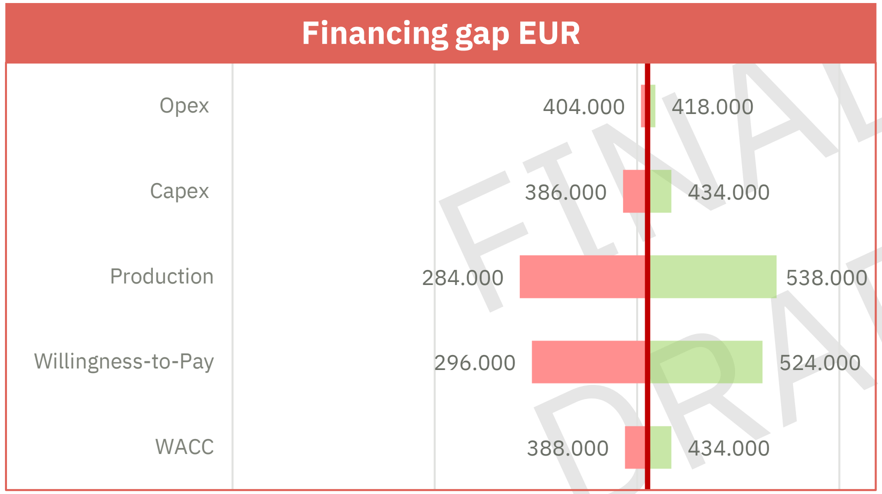
Key value drivers are production costs and willingness to pay

Sensitivities of the key parameters

Multiple sensitivities were applied to the business case as described in the slides above. Of the key parameters, a 10% increase and 10% decrease is shown. As is visible in the graph, the most important value drives are the production costs of hydrogen and the willingness-to-pay by the off-takers. Therefore, the shown financing gap on slide 35 depends greatly on the assumptions taken for these figures.

Sensitivity	
Impact on Opex	+10% / -10%
Impact on Capex	+10% / -10%
Impact on Production Cost	+10% / -10%
Impact on Willingness-to-pay	+10% / -10%
Impact on WACC	+1% / -1%





* Source: large aggregator
** These costs are not inflated
*** These costs are only partly inflated

Section 6: Financial gap analysis

Financial gap analysis

A five-step approach clearly identifies the necessary interventions needed to close the financial gap of the business case

1
Quantify the financial gap of the business case
Included in Section 6

2
Determine key criteria and risks to focus on *(what will have the most impact)*
Included in Section 6

3
Create overview of possible interventions
Included in Section 6

4
Select the necessary interventions
Included in Section 6

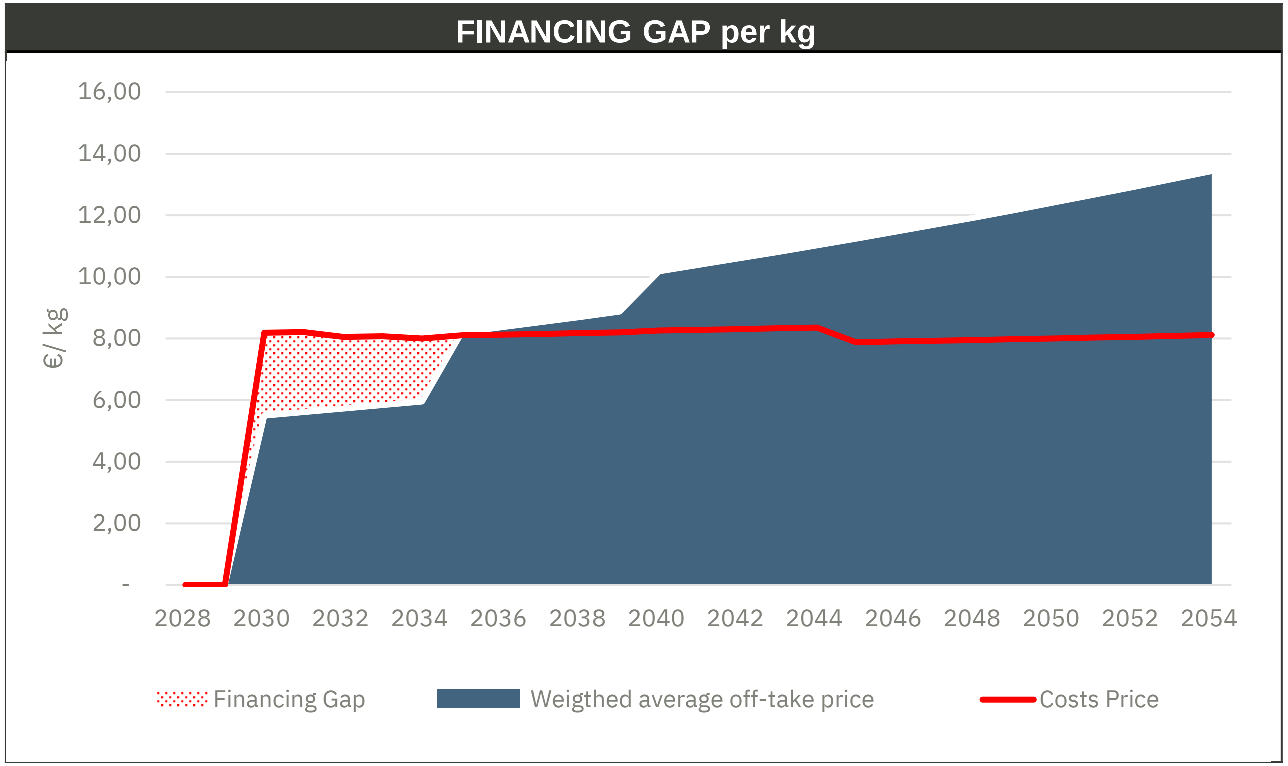
5
Discuss key conclusions and considerations
Included in Section 7

Problem orientated (steps 1–2)

Solution orientated (steps 3–5)

Step 1 | Key conclusions financial gap base case

Financial gap in base case is €~2.3 bn over 10 years; financial surplus over project life



- **Assumptions |** The base case is highly dependent on the underlying assumptions.
- **Green hydrogen costs |** Graph shows a slight decrease in price per kg through the ramp up in volumes from 50 kton to 200 kton in 2034. Due to fixed price contracts and expected price reduction on the shipping costs (a.o.), you will notice a relatively flat price curve as the indexation applied is between 10-15% of the cost price. Lastly, a reduction of 17% is assumed in 2045 for local production price explaining a step down in that year.
- **HPA |** Weighted average off-take price increases with inflation over time. Base case assumes two step ups in the willingness to pay (10% in 2035; 25% in 2040) due to regulations coming into effect.
- **Financial gap |** During the first ten years the project results in negative cashflows, which leads to a total financial gap of €~2,3 bn. However, during the total life of the project due to projected higher HPA prices over time, the base case presents a financial surplus over the project life of over €~2 bn.

Step 2 | Criteria and risks

Multiple criteria such as the financial impact, effectiveness and potential up- and downside function as the value drivers to select the right intervention(s) to close the financial gap

Criteria

1. **Financial Impact |** What is the expected change in the financial gap caused by the intervention?
2. **Mitigates risks |** Does the solution mitigates the identified risks of the business case?
3. **Effectiveness of financial investment |** Is the expected change in the financial gap relatively large compared to the investment made?
4. **Potential upside |** To what extend does the government also benefits from the potential profits?
5. **Potential downside |** To what extend does the government also benefits from the potential profits?
6. **Complexity |** What kind of complexity does the implementation of the intervention contain (execution risk, dependencies etc.)?

Risks to address

1. **Price |** Mismatch between production price and sale price (willingness to pay)
2. **Regulations |** Uncertainty in regulation and other governmental intervention
3. **Offtake |** Uncertainty in offtake green hydrogen (volume and timing)

Risks 1 and 3 need to be addressed in order for projects to reach FID. A **mix of multiple interventions is required** and increases the chance to mitigate the different risks, since they address different risk areas (regulations, financial, market dynamics).

Step 3 | Overview possible interventions

The list of possible interventions exists out of financial products, rules and other mitigations*

	Interventions	Risk	Rationale	Explanation	Financial gap (negative cashflow years)	Net Government (over project life)
	Base case				2,300 mn	0
Financial product	**Capex subsidy****	1	Reducing capital investment and lowering the investment hurdle	500 mn subsidy upfront	1,400 mn	- 500 mn
Financial product	**Opex subsidy****	1,3	Creates price certainty for an extended period of time	15-year opex subsidy for terminal operator at a price of € 7,- per kg.	1,600 mn	-700 mn
Financial product	**Two-sided CfD****	1,3	Creates price certainty for an extended period of time and potential upside	15-year two-sided contract for difference at a price of € 8.25,- per kg	0 mn	-2,100 mn
Financial product	**Two-sided CfD****	1,3	Creates price certainty for an extended period of time and potential upside	25-year two-sided contract for difference at a price of € 8.25,- per kg	0 mn	1,400 mn
Financial product	**Subordinated loan terminal**	1	Reducing the capital costs will improve the feasibility of the business case	150 mn (50% of equity) subordinated loan at 5% cost of debt	1,500 mn	0 mn***
Rules	**Regulatory intervention (major)**	2,3	Regulatory intervention (for example a green certificate scheme) creates obligatory offtake	Extra 25% increase in HPA by 2035	1,100 mn	N/A
Other	**Delay project**	0	Starting at a higher willingness to pay	Commence project in 2035, assuming 10% higher capex	2,200 mn	N/A
Other	**Delay project and adjust production cost**	1	Starting at a higher willingness to pay	Commence project in 2035, assuming 10% higher capex and production cost of 2.5 €/kg and 2.0 €/kg after 15 yrs	1,400 mn	N/A

* Other possible interventions not included in the analysis are revenue guarantees (either as possible last resort off-taker or an import guarantee), because the business case assumes the role of an aggregator
*** Assuming no downward (positive) impact on wacc*
***** Assuming payment of loan and excluding interest payment*

Step 4 | Selection of interventions

The interventions are qualitatively scored to select the most suitable solution(s) that closes the financial gap

Criteria	Capex subsidy	Opex subsidy	Two-sided CfD 1.0 *15 years*	Two-sided CfD 2.0 *25 years*	Subordinated loan terminal	Regulatory intervention	Delay project	Delay project *+ adjust production cost*
1. Financial Impact	High (positive)	Medium (medium)	High (positive)	High (positive)	High (positive)	Medium (medium)	Low (negative)	High (positive)
2. Mitigates risks	Medium (medium)	High (positive)	High (positive)	High (positive)	Medium (medium)	High (positive)	Low (negative)	Medium (medium)
3. Effectiveness	High (positive)	Medium (medium)	High (positive)	High (positive)	High (positive)	n/a	n/a	n/a
4. Potential upside	n/a	n/a	High (positive)	High (positive)	Low (negative)	n/a	n/a	n/a
5. Potential downside	n/a	High (negative)	High (negative)	High (negative)	Low (positive)	n/a	n/a	n/a
6. Complexity	Low (positive)	Low (positive)	Medium (medium)	Medium (medium)	Medium (medium)	High (negative)	Medium (medium)	Medium (medium)

+ High
× Low
− Medium
n/a N/A

Positive score
Negative score
Medium score
Not applicable

Based on the selected criteria a form of a CfD and a subordinated loan are the most well-scoring interventions for the business case.

Step 4 | Considerations of the criteria

Details of the selection making process for the interventions

	Capex subsidy	Opex subsidy	Two-sided CfD 1.0 *15 years*	Two-sided CfD 2.0 *25 years*	Subordinated loan terminal	Regulatory intervention	Delay project	Delay project *+ adjust production cost*
1. Financial Impact	> 750 mn	< 750 mn	> 750 mn	> 750 mn	> 750 mn	> 750 mn	< 750 mn	>750 mn
2. Mitigates risks	Addresses only one risk	Addresses multiple risks	Addresses multiple risks	Addresses multiple risks	Addresses only one risk	Addresses multiple risks	Addresses no risks	Addresses one risk
3. Effectiveness	Relatively low budget required (500 mn) compared to impact (900 mn)	Similar budget (~700mn) required compared to impact (~700 mn)	Similar budget (~2,500 mn) required compared to impact (~2,300 mn)[3]	Similar budget (~2,500 mn) required compared to impact (~2300 mn)[3]	Relatively low (150 mn) budget required compared to impact (~800 mn)	NA	NA	NA
4. Potential upside	NA	NA	Possibility for relatively high upside	Possibility for relatively high upside	Small upside potential (refinancing)	NA	NA	NA
5. Potential downside	NA	If price is significantly below strike price for longer periods, high financial exposure	If price is significantly below strike price for longer periods, high financial exposure	If price is significantly below strike price for longer periods, high financial exposure	Risk of not paying back the loan (~150 mn)	NA	NA	NA
6. Complexity	Straightforward and more often applied	Straightforward and more often applied	More complex than a pure opex subsidy	More complex than a pure opex subsidy	Requires financial structuring and documentation knowledge, but relatively well-known	Relatively complex considering timelines, stakeholders and practical implications	Doesn't require major actions	Doesn't require major actions

3. Not taking the upside into account

Section 7: Conclusions and considerations

Step 5 | Conclusions and considerations

Despite a competitive delivered price for liquid hydrogen and a net positive cash flow for the project period there is still a substantial financial gap. This could result in a lack of offtake that delays or curtails projects.

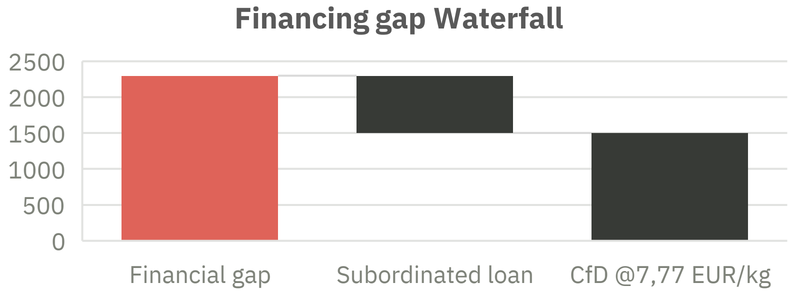
Closing the gap

1. The business case for the import of green hydrogen through the Port of Amsterdam shows a significant financial gap within the first ten years but sees a **potentially positive business case over the life of the project**.
2. To close the (temporary) financing gap and withstand the risks, **government intervention** is deemed necessary. A range of interventions might be suitable to support the import of green hydrogen and **would need to address at least the price and offtake risk**.
3. The sensitivities on the **willingness to pay and cost price show a strong impact** on the business case and financing gap.

Illustrative example

Several **combinations of multiple interventions** could address two key risks identified (price and offtake). For illustration purposes, the following interventions would lead to a closed financial gap. In the base case scenario, the initially invested amounts will be repaid within a 20-year period.

1. € 150 mn subordinated loan to finance the terminal's capex (leading to a lower wacc; ~11%)
2. Due to the positive impact from the subordinated loan, a lower CfD strike price can be implemented. A CfD of € 7,77/kg over a period of 20 years can close the financial gap for the business case.



Budget

The governmental budget needed in order to close the financial gap will depend on the choice of interventions. For example, without other governmental interventions implementing a CfD structure with a € 8.25 strike price would require ~€ 2.5 bn to cover the negative cashflows within the first ten years when the production price is above the willingness to pay. In case a € 150 mn subordinated loan is additionally implemented, a lower strike price can be implemented and the required budget would be reduced to ~ € 1.7 bn. In case, the subordinated loan is combined with the the regulatory intervention scenario, the budget required would be equal to the loan (~ € 150 mn).

Step 5 | Conclusions and considerations

Existing instruments could be adapted or new instruments could be created and should consider the tenor, budget, creditworthiness, and regulation

Establishing effective instrument(s)

The hydrogen market is still in a nascent stage where the long-term securities required to build a business case upon are absent. With a market-only perspective import of hydrogen (derivatives), necessary to fulfil a net zero targets, will not materialize.

To support the development of import capacity in the Netherlands. Existing instruments for import such as H2Global could be adapted, or **new instruments could be devised considering tenor, budget, creditworthiness, and the point of the value chain (see righthand side).**

The establishment of such an instrument will kick-start the necessary investments and steps to be taken; allowing for the signing of many underlying contracts within the total value chain, like investments in facilities and equipment (for example hydrogen ships), contract(s) between the aggregator and the producer, contract(s) between the harbour and terminal operator, and contracts between the aggregator and the off-takers.

Longer tenors for supply as well as offtake contracts. For the supply side at least 15 years should be considered. Moreover, certain off-takers, especially those that need to take investments decisions, will require longer sales contracts. Finally, longer tenors for a CfD like instrument allow for a potential upside for the government.

Larger budgets will be fundamental to realize import at scale. The estimated € 2,300 mn financing gap for this single 200ktpa project in the port of Amsterdam is nearly 8x the available €300 mn budget for the Netherlands trough H2 global.

Creditworthiness of off-taker(s) is essential for bankable project. Given the large scale of import projects few parties are expected to be able to guarantee offtake of the full capacity. Without the presence of a creditworthy aggregator additional guarantees might be required to secure the project.

The point in the value chain and how the instruments will land will determine the impact. Instruments could be primarily targeted at the terminal operator, the aggregator, or off-takers.

Step 5 | Conclusions and considerations

Initial reflections on the business case highlight the significant role of the aggregator given scattered hydrogen demand and the financial gap's sensitivity to the underlying assumptions

Considerations

Business case assumptions

- The analysis of the business case shows a competitive delivered price for liquid green hydrogen of ≥200 kton/year compared to local production and a net positive cash flow for the project period. However, the business case has to overcome a substantial financing gap for the first 10 years. Although the existence of the financing gap is certain, the depth and the duration depends on the applied assumptions (the delivered price and the WtP).
- Regulations for different subsectors are likely to impact the base case and may drive the willingness to pay in the future but are difficult to quantify at this stage.

Aggregator role

- The offtake potential for green hydrogen through the Port of Amsterdam is only partially reliant on the NSCA. The involvement of an aggregator contributes to the success of the Port of Amsterdam business case managing potential offtake within the NSCA and the scattered offtake potential beyond the area.
- In the base case the aggregator provides the necessary commitment to give comfort to financing parties regarding offtake. This assumes required guarantees are provided by the aggregator.
- Without an aggregator, parties within the value chain will likely require another form of guarantee for volumes and price. Given the large minimum capacity of an import terminal (200 Ktpa) it seems unlikely that this guarantee can be borne by a single off-taker. Hence, additional interventions might be required that may incentivize a specific party or sector.

National interests

- In this business case the hydrogen demand is split between the Netherlands and Germany. If and how the financing gap should be split between the corresponding governments is not in scope of this study and should be examined.

Section 8: Recommendations

Recommendations

Further research is needed to support the business case

Recommendations

- To mitigate the financing gap, governmental intervention in the form of financial instruments or regulatory requirements are deemed necessary. The choice for the intervention method will depend on multiple factors, including geopolitical, economic and financial ones. The Dutch government needs to assess if interventions focused on (a) specific subsector(s) that are tied to the Dutch economy will be given priority or would prefer an intervention to ensure an overall minimum volume of green hydrogen through the Port of Amsterdam.
- Clarity on impact from regulatory interventions such obligatory targets for the use of green molecules can increase the WtP of off-takers, thereby reducing the need for financial interventions. It is therefore recommended to first take these into account when considering the creation of financial instruments.
- The strategic importance of import of green hydrogen through the Port of Amsterdam will need to be considered within the Dutch Hydrogen Roadmap.
- The case could be an example for other import cases within the Netherlands (and/or) Europe. This will need to be assessed.

Further analysis

- The presented business case is based on limited data. Market consultation did not include all potential offtake sectors and was comprised of a limited number of parties within each sector. The accuracy of the business case assumptions will be reviewed on completion of further studies.
- Additionally, further analysis on the implications of regulatory requirements (incl. RED III) for the relevant sectors would give a better understanding of the price competitiveness and necessary governmental interventions for each sector.
- The aggregator plays a significant role in taking on price and volume risk. The contractual arrangements and contract conditions needs to be further assessed (including price point for total volume).
- Depending on the transportation cost per chosen carrier (slide 17), a financial gap for other import carriers, other than liquid hydrogen, can be expected as well. It should be analyzed how the interventions presented in this study could be applied in a broader context.

Section 9: References and glossary

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Glossary

Bn	Billion
CCS	Carbon capture and storage
CfD	Contract for Difference
DEI	Demonstration Energy Innovation
DRI	Direct Reduced Iron
E-SAF	Syntethic Aviation Fuel
ETS	Emission Trading System
EU	European Union
FID	Financial Investment Decision
GW	Gigawatt (10^9 watt)
H2	Hydrogen
IPCEI	Important Project of Common European Interest
Kton	Kiloton
Ktpa	Kiloton per annum
LH2	Liquid Hydrogen
LHOC	Levelized Cost of Hydrogen
LOHC	Liquid Organic Hydrogen Carriers
LNG	Liquefied Natural Gas (vloeibaar aardgas)
Mton	Megaton
Mn	Million
MW	Megawatt (10^6 watt)
NL	the Netherlands
NPE	'Nationaal Plan Energie' – Dutch National Energy Plan
NSCA	North Sea Canal Area
NW-EU	North-West Europe
OWE	Subsidieregeling Opschaling volledig hernieuwbare Waterstofproductie via Elektrolyse
PJ	Petajoule (10^{15} joule)
PoA	Port of Amsterdam
RFNBO	Renewable Fuels of Non-Biological Origin
RED	Renewable Energy Directive, "RED III" refereert naar de meest recente herziene versie hiervan.
SDE	"Stimulering Duurzame Energieproductie en Klimaattransitie", Dutch subsidy scheme to promote national sustainable energy production and the climate transition
SMR	Steam Methane Reformer
TWh	Terawattuur (10^9 kilowattuur)
VEKI	Versnelde KlimaatInvestering Industrie – Dutch subsidy for the industry
Wacc	Weighted Average Cost of Capital
WtP	Willingness to Pay
UAE	United Arabic Emirates